

EGG-ER-11101  
December 1993



**Idaho  
National  
Engineering  
Laboratory**

*Managed  
by the U.S.  
Department  
of Energy*

# TECHNICAL MEMORANDUM FOR THE WAG 3 AND WAG 10 SOILS TREATABILITY STUDY: PHYSICAL SEPARATION OF RADIONUCLIDES IN SOILS

D. Gombert  
T. K. Honeycutt  
J. H. Goettsche  
G. M. Huestis  
T. J. Tranter



Work performed under  
DOE Contract  
No. DE-AC07-76ID01570

<b>Received WAG-10</b>		
DEC 21 1993		
Action	Info	File

**TECHNICAL MEMORANDUM FOR THE  
WAG 3 AND WAG 10 SOILS TREATABILITY STUDY:  
PHYSICAL SEPARATION OF RADIONUCLIDES IN SOILS**

**D. Gombert  
T. K. Honeycutt  
J. H. Goettsche  
G. M. Huestis  
T. J. Tranter**

**Published December 1993**

**Idaho National Engineering Laboratory  
EG&G Idaho, Inc.  
Idaho Falls, Idaho 83415**

**Prepared for the  
U.S. Department of Energy  
Office of Environmental Restoration and Waste Management  
Under DOE Idaho Field Office  
Contract DE-AC07-76ID01570**

# CONTENTS

ACRONYMS .....	vii
1.0 INTRODUCTION .....	2-1
2.0 FIELD SAMPLING .....	2-1
2.1 Sample Location Selection.....	2-1
2.1.1 WAG 1 - Test Area North.....	2-1
2.1.2 WAG 2 - Test Reactor Area.....	2-4
2.1.3 WAG 3 - Idaho Chemical Processing Plant.....	2-7
2.1.4 WAG 5 - Power Burst Facility/Auxiliary Reactor Area .....	2-12
2.1.5 WAG 6 - Experimental Breeder Reactor No. 1 .....	2-19
2.1.6 WAG 7 - Radioactive Waste Management Complex .....	2-22
2.1.7 WAG 9 - Argonne National Laboratory - West.....	2-24
2.2 Sample Collection .....	2-24
3.0 LABORATORY ANALYSES .....	3-1
3.1 Physical Analyses and Treatment .....	3-1
3.1.1 Sample Preparation .....	3-1
3.1.2 Particle Size Analysis.....	3-3
3.1.3 Particle Attrition.....	3-6
3.2 Radiological Measurements .....	3-9
3.2.1 Gamma Spectrometry .....	3-9
3.2.2 Gross Alpha and Gross Beta .....	3-11
4.0 RESULTS .....	3-1
4.1 Particle Size Analysis.....	4-1
4.2 Particle Attrition.....	4-8
4.3 Radiological Measurements .....	4-12
4.4 Data Limitations and Measurement Uncertainties .....	4-20
4.4.1 Data Limitations.....	4-20
4.4.2 Measurement Uncertainties.....	4-21
5.0 CONCLUSIONS AND RECOMMENDATIONS .....	5-1
5.1 Volume Reduction .....	5-1
5.2 Recommended Tasks .....	5-3
6.0 REFERENCES.....	6-1
APPENDIX A - Radionuclide and Particle Size Data .....	A-1
APPENDIX B - Summary of Soil Characteristics and Soil Washing Technologies .....	B-1

## FIGURES

1-1. Location of INEL WAGs.....	1-2
2-1. Sample location for TSF-09 site. ....	2-2
2-2. Sample location for TSF-07 site. ....	2-3
2-3. Sample location TSF-03 outside WAG-1. ....	2-5
2-4. Sample location for TRA-13 site. ....	2-6
2-5. WWP sample location outside WAG-2. ....	2-8
2-6. Sample location for CPP-22 site. ....	2-9
2-7. Sample location for CPP-13 site. ....	2-10
2-8. Sample location for CPP-03 site. ....	2-11
2-9. Sample location for CPP-11 site. ....	2-13
2-10. Sample location outside WAG-3. ....	2-14
2-11. Sample locations for the ARA-06 site. ....	2-15
2-12. Sample location for the PBF-22 site. ....	2-17
2-13. Sample location outside ARA. ....	2-18
2-14. Sample location for the BORAX-08 site. ....	2-20
2-15. Sample location for the EBR-15 site. ....	2-21
2-16. Sample location for the OU 7-05 site. ....	2-23
2-17. Sample location outside WAG-7. ....	2-25
2-18. Location of ANL-W interceptor canal. ....	2-26
2-19. Sample location for the WAG-9 site. ....	2-27
4-1. Particle size distribution as cumulative weight percent for the WAG-1 (TAN) as-received samples. ....	4-3
4-2. Particle size distribution as cumulative weight percent for the WAG-2 (TRA) and WAG-3 (ICPP) as-received samples. ....	4-4
4-3. Particle size distribution as cumulative weight percent for the WAG-5 (PBF) and WAG-9 (ANL-W) as-received samples. ....	4-5
4-4. Particle size distribution as cumulative weight percent for the WAG-6 (EBR-I) and WAG-7 (RWMC) as-received samples. ....	4-6
4-5. Particle size distribution as cumulative weight percent for sample locations associated with aqueous deposition of dissolved species. ....	4-9
4-6. Particle size distribution as cumulative weight percent for sample locations associated with airborne distribution of fine particulate. ....	4-10
4-7. Particle size distribution as cumulative weight percent for sample locations associated with physical distribution by artificial means or gross water movement. ....	4-11

## FIGURES

4-8. Cumulative weighted average $^{137}\text{Cs}$ concentration of individual soil fractions for the WAG-1 (TAN) as-received samples. ....	4-13
4-9. Cumulative weighted average $^{137}\text{Cs}$ concentration of individual soil fractions for the WAG-2 (TRA) and WAG-3 (ICPP) as-received samples. ....	4-14
4-10. Cumulative weighted average $^{137}\text{Cs}$ concentration of individual soil fractions for the WAG-5 (PBF) and WAG-9 (ANL-W) as-received samples. ....	4-15
4-11. Cumulative weighted average $^{137}\text{Cs}$ concentration of individual soil fractions for the WAG-6 (EBR-1) and WAG-7 (RWMC) as-received samples. ....	4-16
4-12. Cumulative weighted average $^{137}\text{Cs}$ concentration of individual soil fractions for sample locations associated with aqueous deposition of dissolved species. ....	4-17
4-13. Cumulative weighted average $^{137}\text{Cs}$ concentration of individual soil fractions for sample locations associated with airborne distribution of fine particulate. ....	4-18
4-14. Cumulative weighted average $^{137}\text{Cs}$ concentration of individual soil fractions for sample locations associated with physical distribution by artificial means or gross water movement. ....	4-19

## TABLES

4-1. Sieve number and corresponding particle size range. ....	4-2
4-2. WAGs grouped on the basis of general soil type. ....	4-2
4-3. Postulated mode of deposition for sample locations. ....	4-7
5-1. Volume reduction for selected residual $^{137}\text{Cs}$ activity levels. ....	5-2

## ACRONYMS

ACMM	Analytical Chemistry Methods Manual
ARA	Auxiliary Reactor Area
ANL-W	Argonne National Laboratory-West
bls	below land surface
BORAX	Boiling Water Reactor Experiment
cpm	counts per minute
CPP	Chemical Processing Plant
D&D	decontamination and decommissioning
DOE	U. S. Department of Energy
DOE-ID	U. S. Department of Energy, Idaho Operations Office
EBR-I	Experimental Breeder Reactor-I
EPA	U. S. Environmental Protection Agency
gpm	gallons per minute
ICPP	Idaho Chemical Processing Plant
IDHW	Idaho Department of Health and Welfare
INEL	Idaho National Engineering Laboratory
NIST	National Institute of Standards and Technology
OU	operable unit
PBF	Power Burst Facility
RCS	radionuclide-contaminated soils
RESL	Radiological and Environmental Sciences Laboratory
RML	Radiation Measurements Laboratory
RPM	Remedial Project Manager
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
SL-1	Stationary Low-Power Reactor No. 1
SPERT	Special Power Excursion Reactor Test
SRM	Standard Reference Material
SRPA	Snake River Plain Aquifer
STA	Sewage Treatment Area
TAN	Test Area North
TRA	Test Reactor Area
TS	treatability study
TSA	Transuranic Storage Area
TSF	Technical Support Facilities
UST	underground storage tank

## ACRONYMS

WAG	waste area group
WCF	Waste Calcining Facility
WERF	Waste Experimental Reduction Facility
WINCO	Westinghouse Idaho Nuclear Company
WWP	Warm Waste Pond



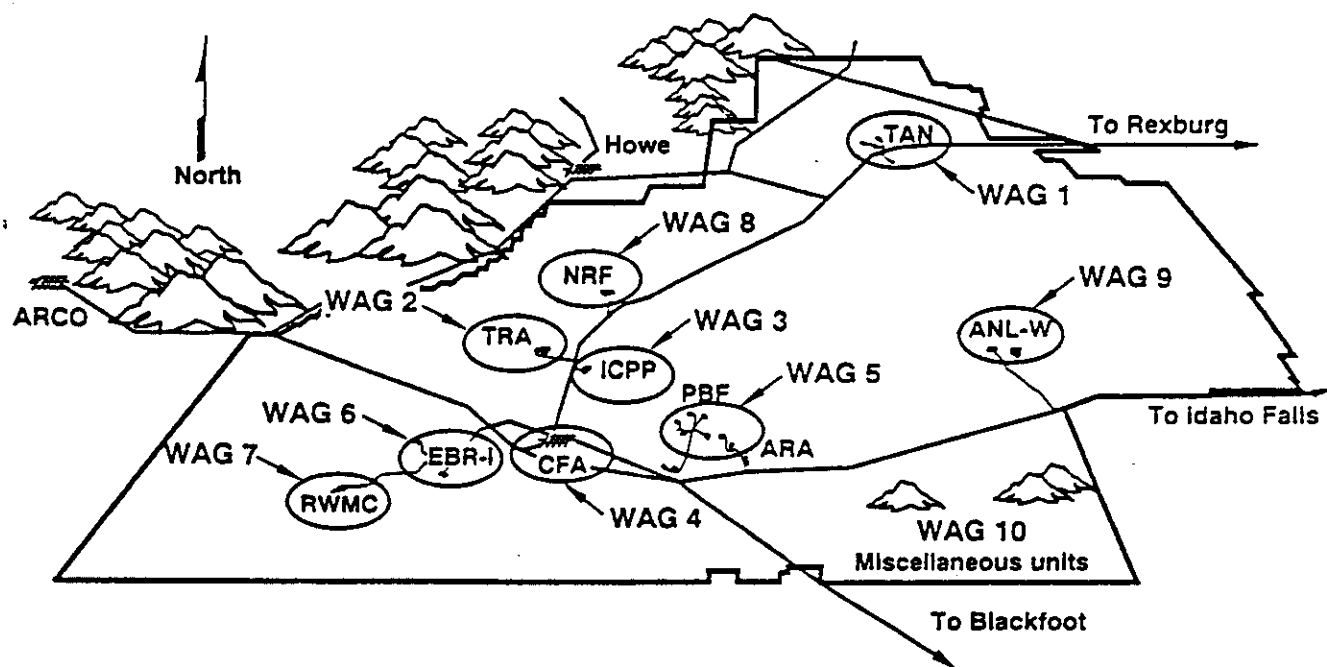
# **TECHNICAL MEMORANDUM FOR THE WAG 3 AND WAG 10 SOILS TREATABILITY STUDY: PHYSICAL SEPARATION OF RADIONUCLIDES IN SOILS**

## **1.0 INTRODUCTION**

This technical memorandum summarizes the results of the first phase of investigation under the Waste Area Group (WAG 3) and WAG 10 Soils Treatability Study (TS). The objective of the first phase of the WAG 3 and WAG 10 TS is to demonstrate whether or not radionuclides can be mechanically separated from soils at the Idaho National Engineering Laboratory (INEL) and make recommendations for future work. If mechanical separation of radionuclides can be economically performed on soils from the INEL, then volume reduction of radioactively contaminated soil at the INEL may be a viable treatment option worthy of further consideration.

To facilitate environmental remediation efforts, the INEL is divided into 10 WAGs which are further subdivided into operable units (OUs). WAGs 1 through 9 generally correspond to INEL operational facilities (Figure 1-1), while WAG 10 corresponds to overall concerns associated with the Snake River Plain Aquifer (SRPA) in the bounds of the facility-specific WAGs. The boundary of WAG 10 is the INEL boundary, or beyond, as necessary to encompass real or potential impact from INEL activities (IDHW 1991).

Sampling was performed in areas of suspected radionuclide contamination in soils from sites inside and outside of existing OUs. Remedial Project Managers (RPMs) of the U.S. Department of Energy (DOE), Idaho Operations Office (DOE-ID), U.S. Environmental Protection Agency (EPA), Region X, and the Idaho Department of Health and Welfare (IDHW) reviewed available information regarding radionuclide contaminated soils (RCS) at the INEL that are outside existing OUs and determined sites where unacceptable risks to human health or the environment may exist. Inside OUs, areas which may have elevated radionuclide contamination in soils and could potentially pose a higher risk were selected for sampling. Surface soils between ranging in depth from 0 to 0.3 m (0 and 1 ft) below land surface (bls) were sampled from the selected locations. Physical separation of particle size fractions was achieved by wet sieving the samples. The individual particle size fractions were analyzed for radionuclide indicators and specific radionuclides. Sample aliquots were subjected to mechanical attrition and the effect of attrition on radionuclide distribution in the individual particle size fractions was evaluated.



- |                                    |  |   |
|------------------------------------|--|---|
| 1. Test Area North                 | 5. Power Burst Facility/Auxiliary Reactor Area | 8. Naval Reactor Facility                                       |
| 2. Test Reactor Area               | 6. Experimental Breeder Reactor                | 9. Argonne National Laboratory-West                             |
| 3. Idaho Chemical Processing Plant | 7. Radioactive Waste Management Complex        | 10. Miscellaneous units including the Snake River Plain Aquifer |
| 4. Central Facilities Area         |  |   |

R93 0067

Figure 1-1. Location of INEL WAGs.

## **2.0 FIELD SAMPLING**

### **2.1 Sample Location Selection**

Surface soil samples were collected from inside the facilities from locations where increased levels of radioactivity may be present from liquid and/or airborne releases. The purpose of soil sample collection was to collect sufficient soil samples which are radionuclide-contaminated for use as the treatable medium for the treatability study. Many of the sites identified for sampling contain only small areas of radioactive contamination and/or low levels of radioactivity; therefore, radiological surveys were performed to locate the highest level of radioactivity for sample collection. Samples were also collected outside of facility fences where possible RCS areas resulting from wind-blown deposition of radionuclides are present. Selection of "outside" sample locations is based on the Radiological and Environmental Sciences Laboratory (RESL) data and sample location maps.

#### **2.1.1 WAG 1 - Test Area North**

##### ***2.1.1.1 Site TSF-09, TSF Intermediate Level Waste Disposal System.***

Sampling was conducted at Technical Support Facility (TSF)-09 which consists of three abandoned underground storage tanks (USTs) known as the Test Area North (TAN) V-tanks (Figure 2-1). The site is located in an open area east of TAN-616 and north of TAN-607. The V-tanks were installed between 1957 and 1958 to store and treat radioactive wastewater and other liquid radioactive waste at TAN (EG&G 1993a).

A 15.2- x 24-m (50- x 80-ft) surface area above the tanks was radioactively contaminated from spills when the V-tanks were emptied and from runoff from the adjacent cask storage pad. Disposal of chemicals for weed control purposes may also have contaminated the area. Soil sample data from a 1982 decontamination and decommissioning (D&D) project confirm that high concentrations of cesium (Cs)-137, cobalt (Co)-60, and strontium (Sr)-90 are present in the shallow surface soils around the V-tanks. The original ground surface around the V-tanks has been built up gradually over the past 20 years. Soil was used as a cover to shield radioactivity and to reduce the potential for off-site migration. Sampling was performed on the area of highest radionuclide contamination as identified through an initial soil survey (Figure 2-1).

***2.1.1.2 Site TSF-07, TSF Disposal Pond.*** Construction of the TSF-07 disposal pond and common sump (TAN-655) began in 1971 and was completed in late 1972 (Figure 2-2). The pond was constructed to replace the TSF injection well, which was used until September 1972. The disposal ponds are located in an unlined, diked area encompassing approximately 35

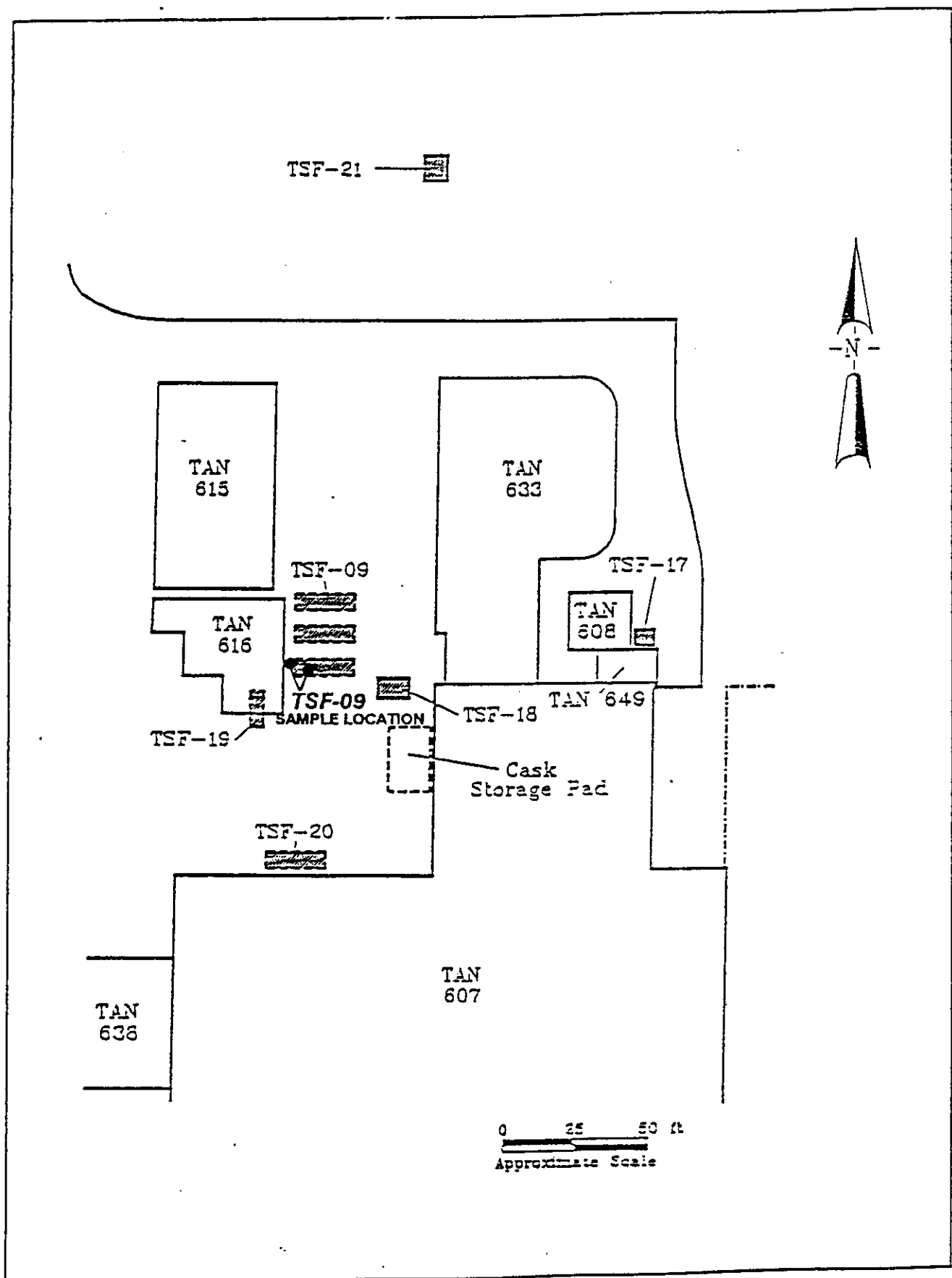


Figure 2-1. Sample location for TSF-09 site.

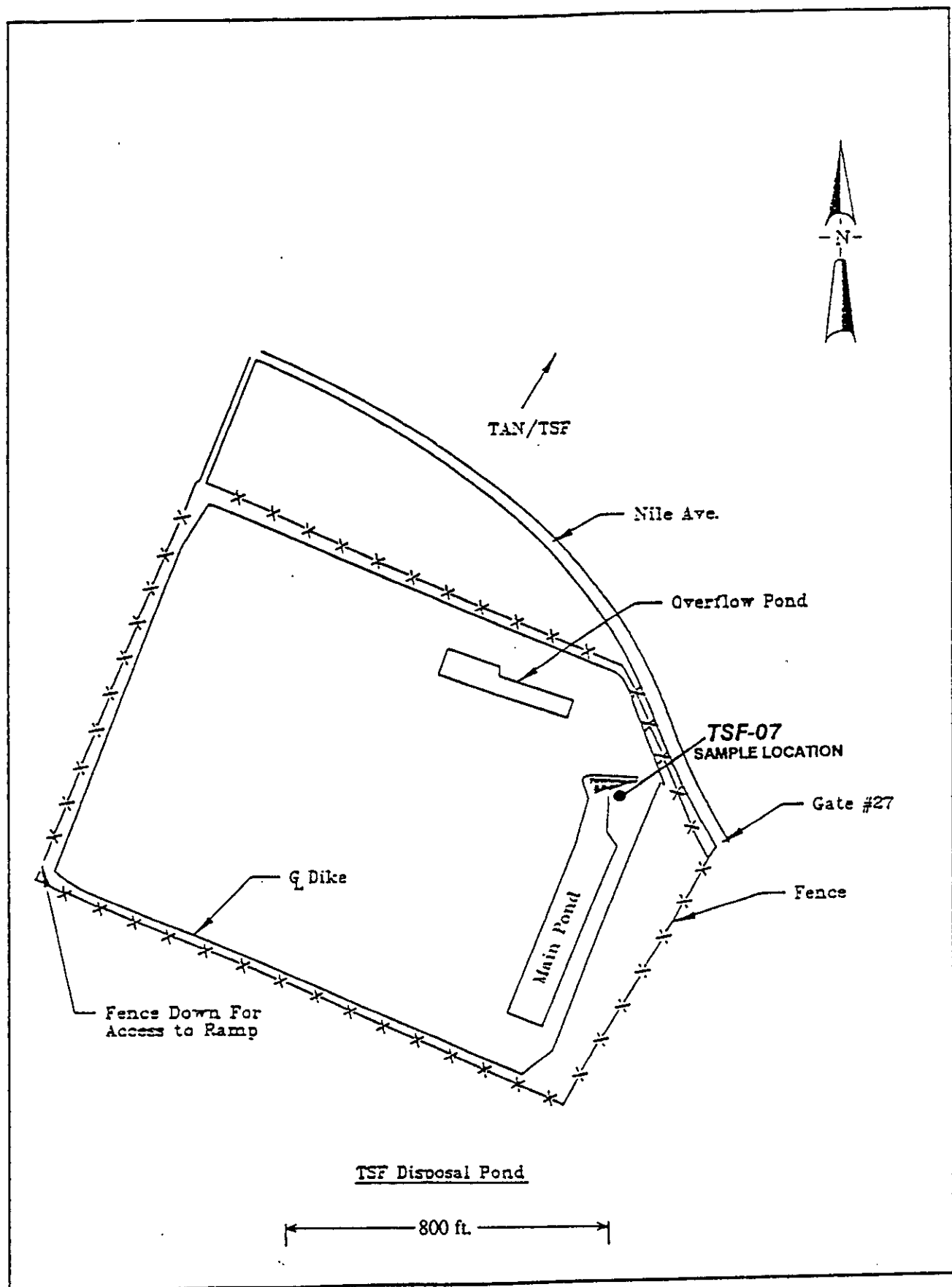


Figure 2-2. Sample location for TSN-07 site.

acres. The TSF disposal ponds consist of a main pond and an overflow pond and are located in the northeast corner of the diked area. The main and overflow ponds comprise only a small portion of the diked area. A 0.3 m (1 ft) diameter galvanized steel pipe discharges materials from the sump to the ponds (EG&G 1993b).

The TSF-07 disposal pond receives effluent from a variety of sources, which include low-level radioactive waste, cold process water, and treated sewage effluent. This waste is mixed in the common sump at TAN-655 and pumped to the TSF-07 disposal pond. The disposal ponds receive effluent from the trickling filter sewage treatment plant, boiler blowdown from the TAN-603 Service Building, and process wastes from the regeneration of water softeners. Prior sampling of the TSF-07 disposal pond has detected Cs-137, Co-60, Sr-90, and gross alpha activity in the surface soils of the pond. The highest concentrations of radioactive contaminants were found in the inlet area of the main pond. Sampling was performed in the vicinity of the inlet on pond soils containing the highest levels of radioactivity, as determined by the radiological field survey (Figure 2-2).

**2.1.1.3 Sample Location Outside WAG-1.** Review of raw RESL data (1981) and maps identified sample location TSF-3 southeast of the TSF Sewage Treatment Plant as having Cs-137 concentrations of approximately 24 picocuries per gram (pCi/g) (Figure 2-3) in 0- to 5-cm surface soils. A sample was collected near this location from surface soils that have the highest level of radioactivity as determined by field screening (Figure 2-3).

## **2.1.2 WAG 2 - Test Reactor Area**

**2.1.2.1 Site TRA-13, TRA Sewage Leach Ponds by TRA-732.** The Sewage Treatment Area (STA) is located 46 m (150 ft) east of the Test Reactor Area (TRA) security fence (Figure 2-4) and is comprised of an Imhoff tank, trickling filter, chlorination basin, sludge pit, and leach pond containing two cells into which effluent is discharged. The dimensions of the northern cell, constructed in 1965 (65 cell), are approximately 76 x 15 x 4 m (250 x 50 x 14 ft), and the dimensions of the southern cell, constructed in 1950 (50 cell), are approximately 76 x 24 x 6 m (250 x 80 x 18 ft). Since 1952, the system has been used continuously, receiving effluent from sanitary sewer drains throughout TRA at average discharges of 20 to 30 gallons per minute (gpm). Effluent to the leach ponds has been routinely monitored by the Environmental Monitoring Unit since 1986 (EG&G 1993c).

Soil samples collected in August 1992 between 0 and 0.1 m (0 and 0.3 ft) bls from the southeast corner of 50 cell detected Cs-137 at 136 pCi/g, Co-60 at 60 pCi/g, and low levels of several other gamma-emitting radionuclides. The sample results also showed low levels of

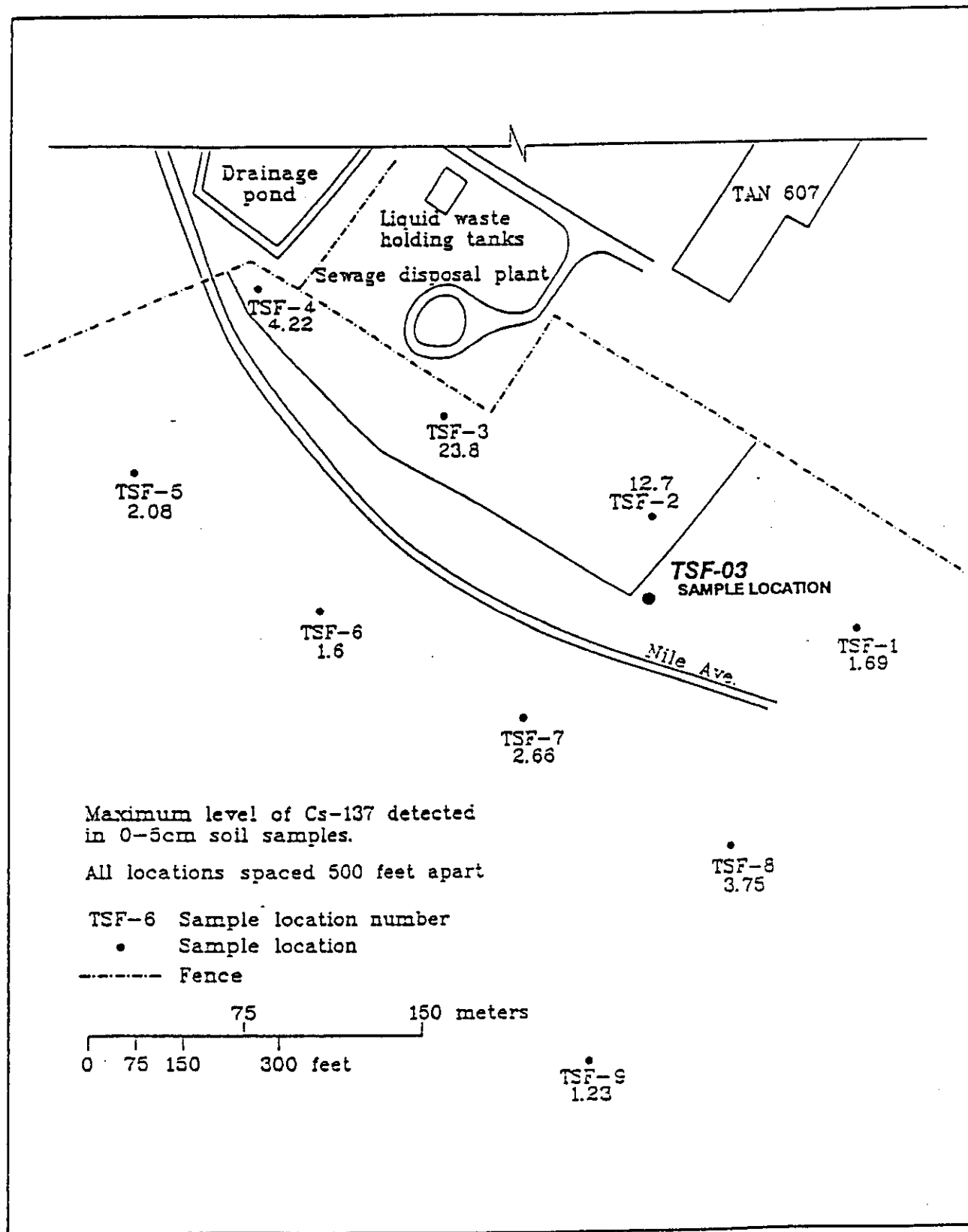


Figure 2-3. Sample location TSF-03 outside WAG-1.

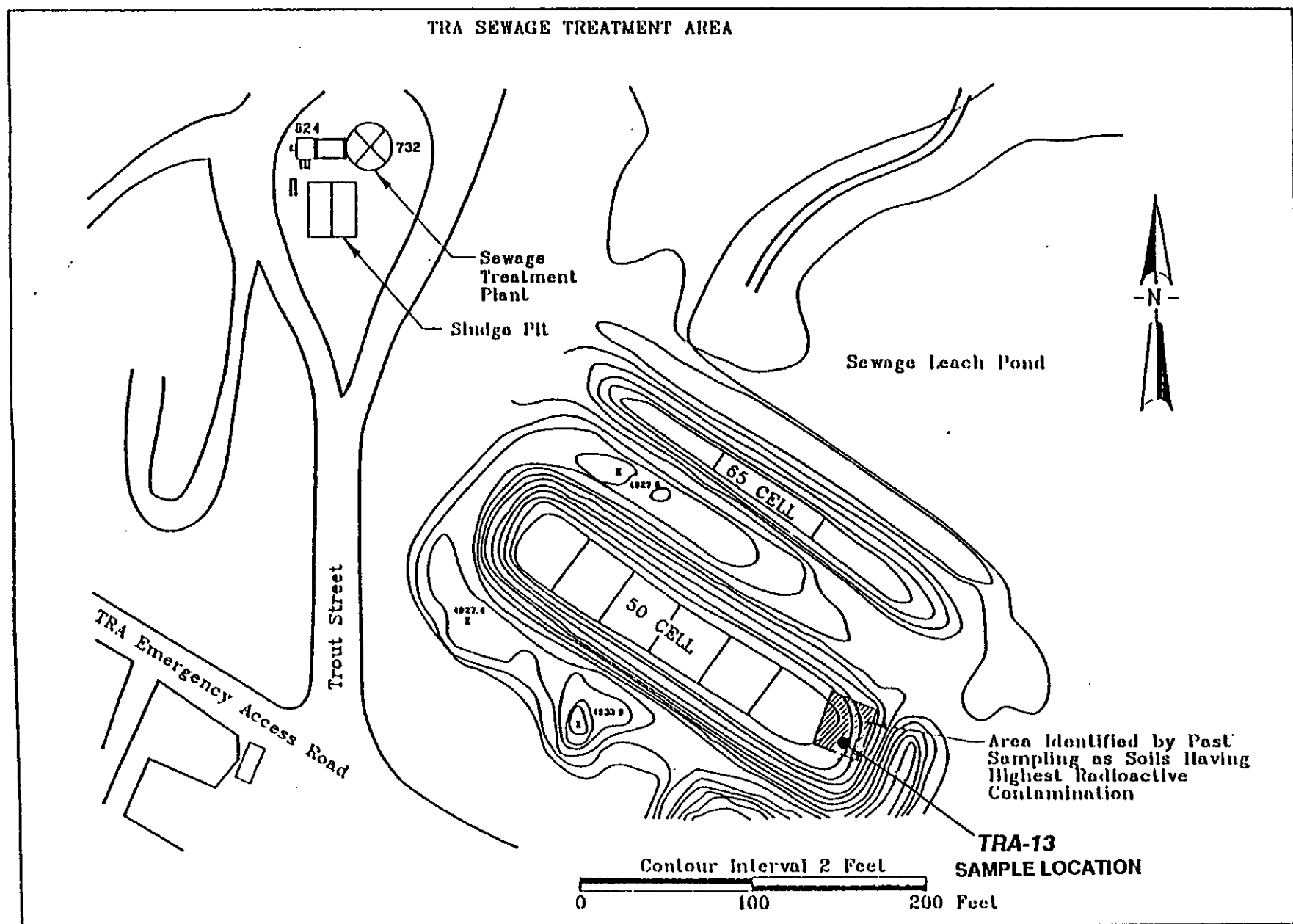


Figure 2-4. Sample location for TRA-13 site.



several alpha-emitting radionuclides [plutonium (Pu)-239/240, uranium (U)-234, and U-235]. Sampling for the TS was performed on soil from the southeast area of 50 cell (Figure 2-4).

**2.1.2.2 Sample Location Outside WAG-2.** Areas north of the TRA Warm Waste Pond (WWP) have been identified in past sampling investigations as containing RCS. However, past activities at the TRA WWP have included removal of radionuclide-contaminated surface soils to reduce the levels of radioactivity in the soils. Soils containing elevated levels of radioactivity have been previously identified approximately 250 m (820 ft) north of the TRA WWP (Figure 2-5). Soils were sampled on the north side of the pond where the highest radionuclide concentrations were identified by the radiological field survey (Figure 2-5).

### **2.1.3 WAG 3 - Idaho Chemical Processing Plant**

**2.1.3.1 Site CPP-22, Particulate Air Release South of CPP-603.** The Chemical Processing Plant (CPP)-22 site is located to the south of building CPP-603 where surface soil was contaminated by an air release of radionuclide particulate (Figure 2-6). This release occurred in October 1958 when the cell ventilation filters failed. The surface soils adjacent to building CPP-603 were contaminated; however, the contamination was reportedly cleaned up. The CPP-22 site is a triangular area with an approximate area of 131,300 feet<sup>2</sup> (Figure 2-6). Soil sampling was conducted in the area containing the highest level of radioactivity as determined by radiological field survey (Figure 2-6).

**2.1.3.2 Site CPP-13, Pressurization of the Solid Storage Cyclone NE of CPP-633.** Site CPP-13 contains radionuclide-contaminated soil from a release from the Solids Transport System at the Waste Calcining Facility (WCF) (Figure 2-7). During an attempt to clear the solids storage cyclone, the cyclone inadvertently pressurized and released contaminated dolomite solids. This release contaminated the vault and an area of approximately 300 ft to the northeast of building CPP-747. The release reportedly contained 230 mCi of Sr-90, 40 mCi of ruthenium (Ru)-106, and 230 mCi of Cs-137. Radiation levels of 250 to 750 mrem/hr were found on top of the vault, with significantly lower levels measured away from the building. The majority of the contamination was removed from the vault rooftop and surrounding area. Figure 2-7 shows the sample location for the CPP-13 site.

**2.1.3.3 Site CPP-03, Temporary Storage Area SE of CPP-603.** Site CPP-03 is an area that was used to store old and abandoned radiologically-contaminated equipment (Figure 2-8). This storage area was decommissioned in the 1970s and all stored material was packed into standard wooden boxes and taken to the Radioactive Waste Management Complex (RWMC). During this effort, most of the contaminated dirt was also removed, boxed, and sent to the

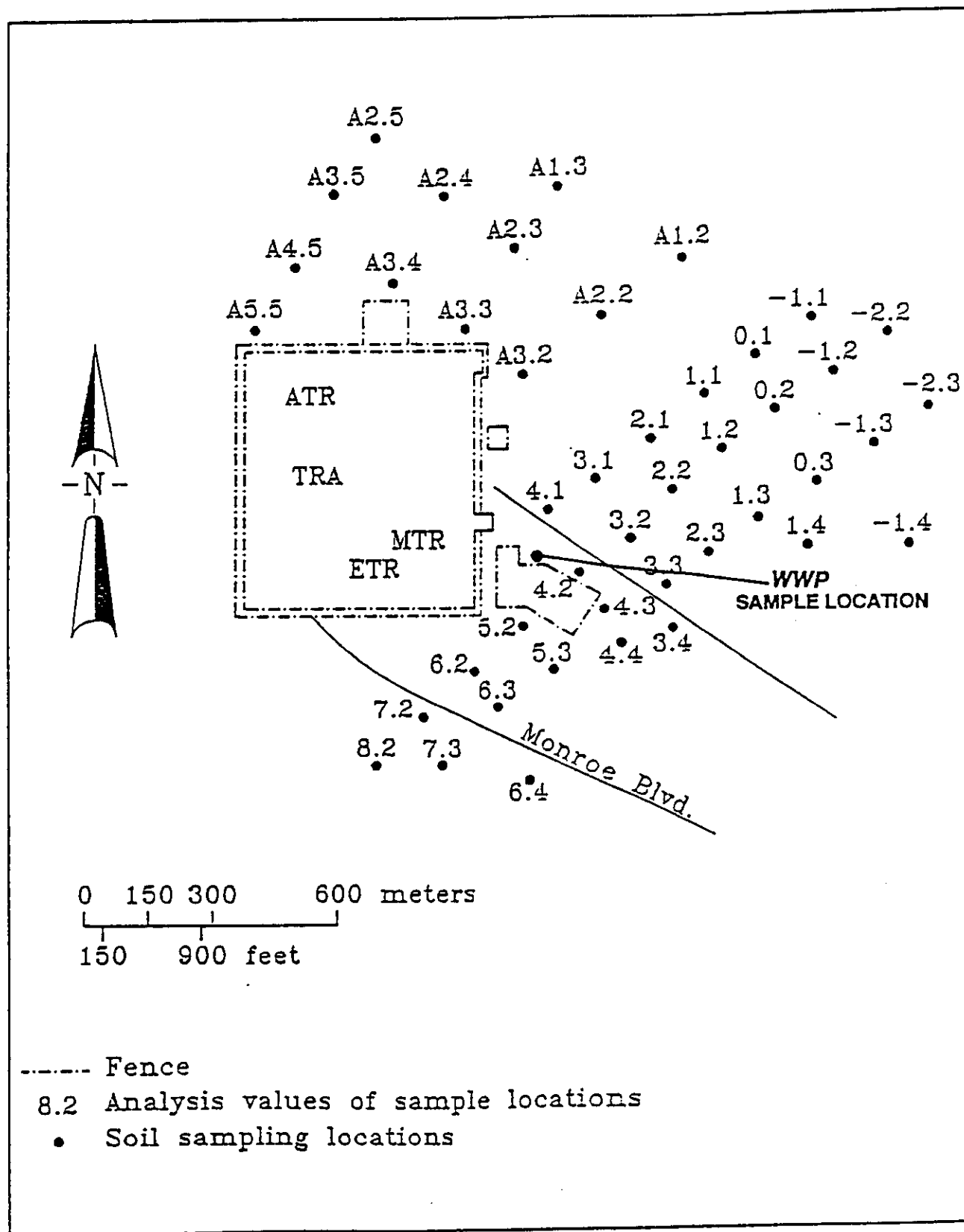
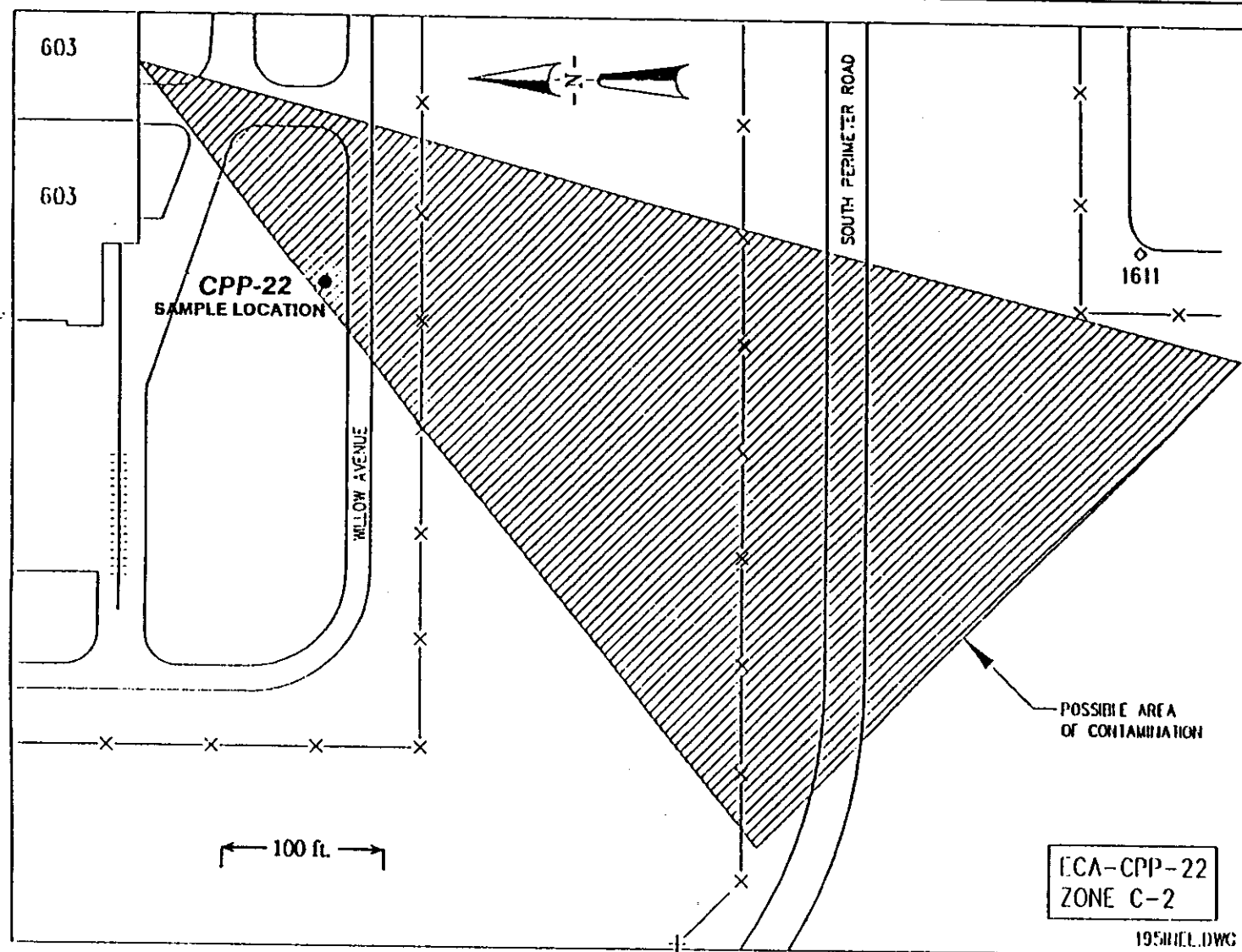
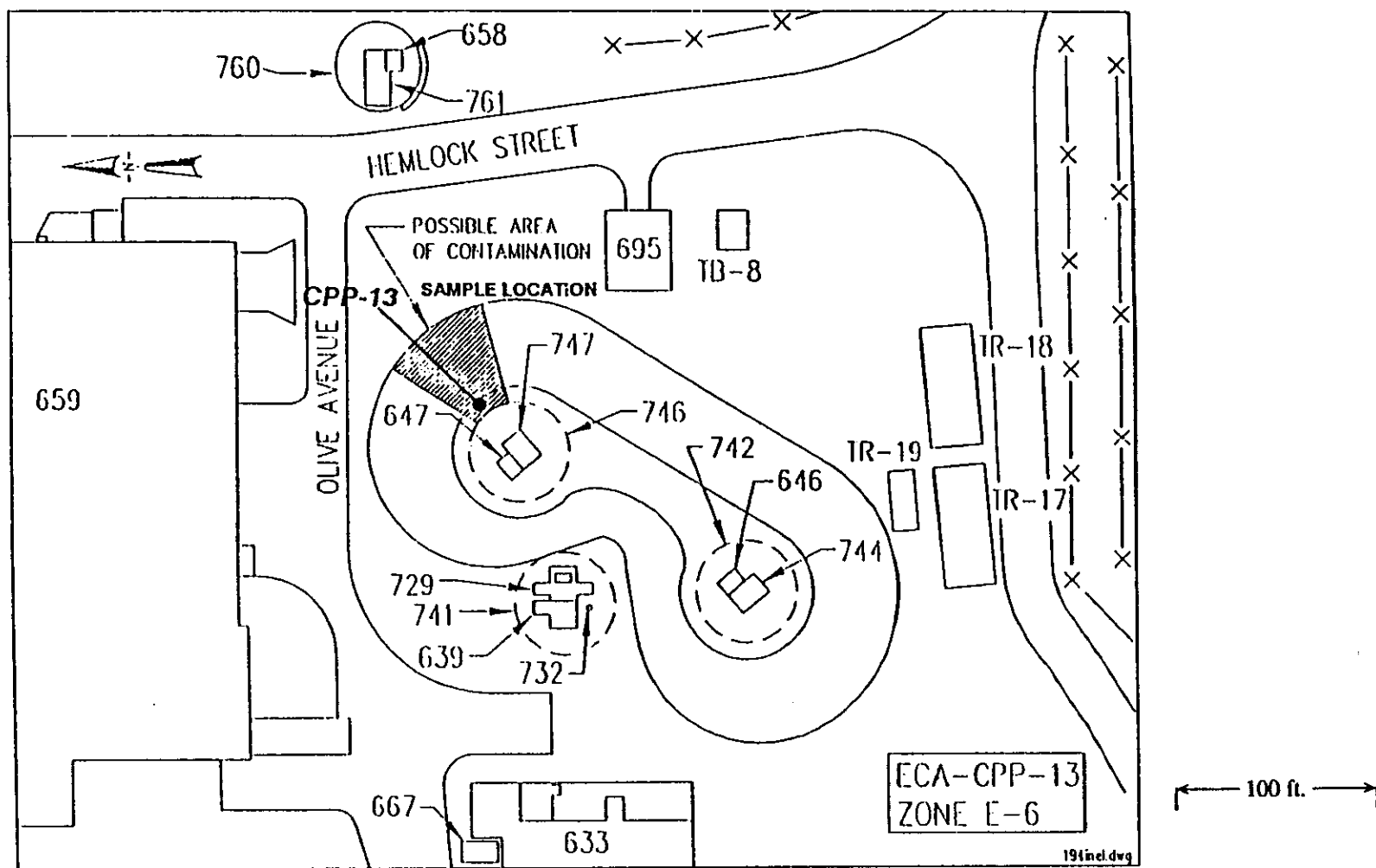


Figure 2-5. WWP sample location outside WAG-2.



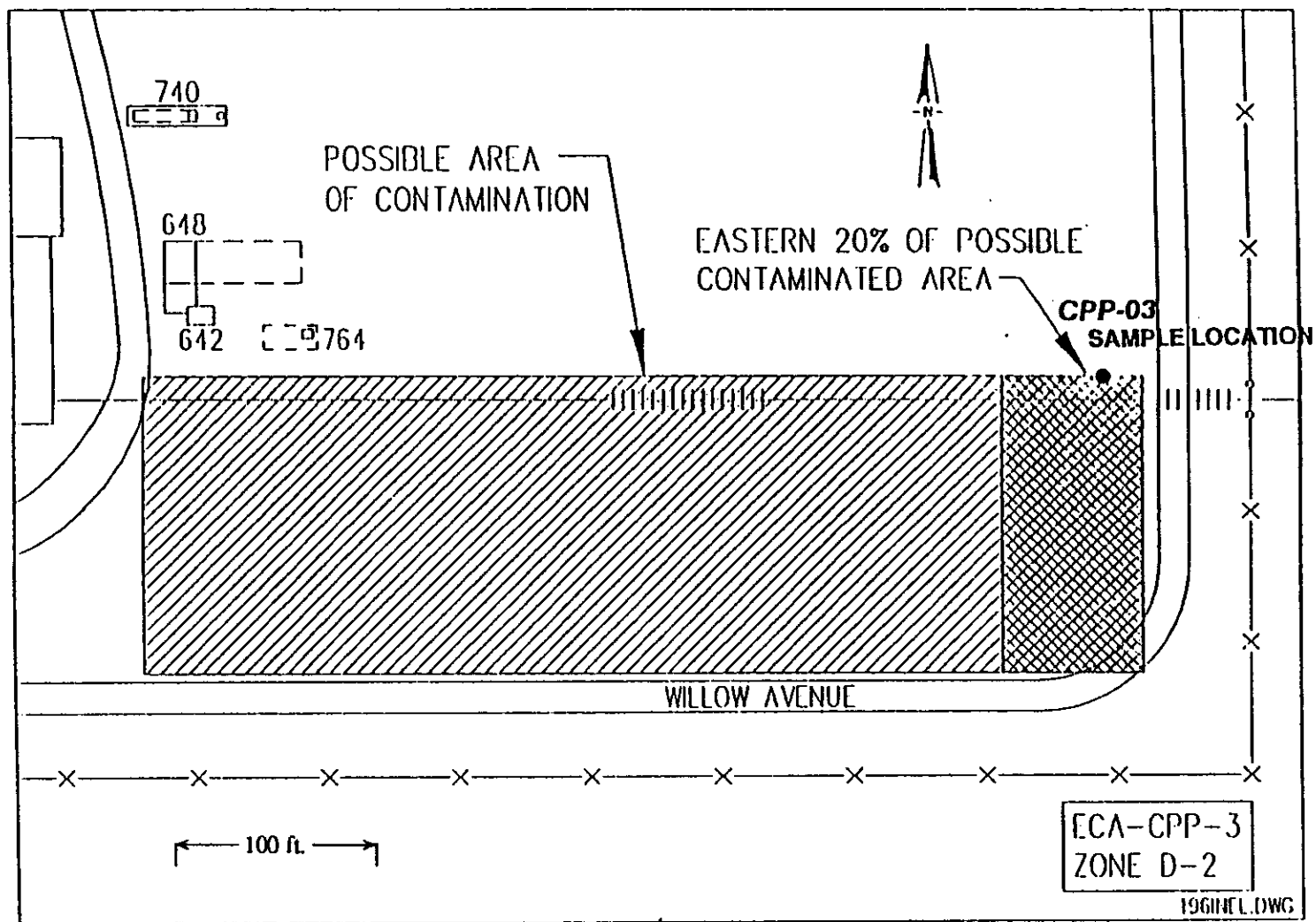
Site CPP-22 (Particulate Release South of CPP-603).

Figure 2-6. Sample location for CPP-22 site.



CPP-13 (Pressurization of The Solid Storage Cyclone NE of CPP-633).

Figure 2-7. Sample location for CPP-13 site.



CPP-03 (Temporary Storage Area SE of CPP-603).

Figure 2-8. Sample location for CPP-03 site.

RWMC. Approximately 28 cm (11 in.) of clean soil was then placed over the area. Recent surface radiation surveys detected elevated levels in the extreme eastern 20% of the storage area, averaging approximately 6 mrem/hr. This elevated radiation may have been due to the past storage of approximately 12,000 yds<sup>3</sup> of contaminated soil that was excavated from the Tank Farm area and stockpiled at this location prior to burial in the trenches located in the northeast corner of the Idaho Chemical Processing Plant (ICPP) (ECA CPP-34). Figure 2-8 shows the sample location for the CPP-03 site.

**2.1.3.4 Site CPP-11, Sludge and Water Release.** Site CPP-11 contains soil that was contaminated with wastes containing both sludge and basin water from an accidental tank release (Figure 2-9). The dimensions of the spill were estimated to be 28 x 56-ft (1,568 ft) and contained approximately 300 to 500 gallons of sludge and liquid contaminated with cerium (Ce), Cs, Co, europium (Eu), niobium (Nb), and Ru. Following the release, localized areas having radiation levels of 1 rem/hr and greater were selectively removed. The remainder of the area was roped off until further decontamination and soil removal could be accomplished. It is uncertain whether this decontamination was ever accomplished. Figure 2-9 shows the location which was sampled at the CPP-03 site.

**2.1.3.5 Sample Location Outside WAG-3.** The raw RESL data (1971 to 1974) show the areas of greatest radioactive contamination outside the area located along a SW-NE axis corresponding to the prevailing wind direction at the ICPP. An extensive grid system used for locating sample locations has been established outside the ICPP area by RESL personnel (Figure 2-10). Two possible sample locations containing RCS are located at grid points A36 and A46 where radionuclide concentrations of Cs-137 in surface soils (0 to 5 cm) have been previously measured up to 37 pCi/g. The grid points are identifiable by metal posts and markings. Grid location A36 is located approximately 2,250 ft NE (45°E of N) of the ICPP Stack, while grid location A46 is located approximately 2,500 ft NNE (22.5°E of N) of the ICPP Stack. A radiological field survey was used to determine the optimal sampling location. Sampling was performed southeast of grid location A46 (Figure 2-10).

#### **2.1.4 WAG 5 - Power Burst Facility/Auxiliary Reactor Area**

**2.1.4.1 Site ARA-06, ARA-II SL-1 Surface Soils.** The Stationary Low-Power Reactor No. 1 (SL-1) burial area is located approximately 489 m (1,600 ft) northeast of Auxiliary Reactor Area (ARA)-II, which was the original site of the reactor before the SL-1 accident in 1961. The SL-1 site is fenced and approximately 183 x 91 m (600 x 300 ft) (Figure 2-11). The SL-1 burial ground actually consists of two separate units, the buried waste and the surficial contamination. The surficial contamination is responsible for a direct radiation exposure

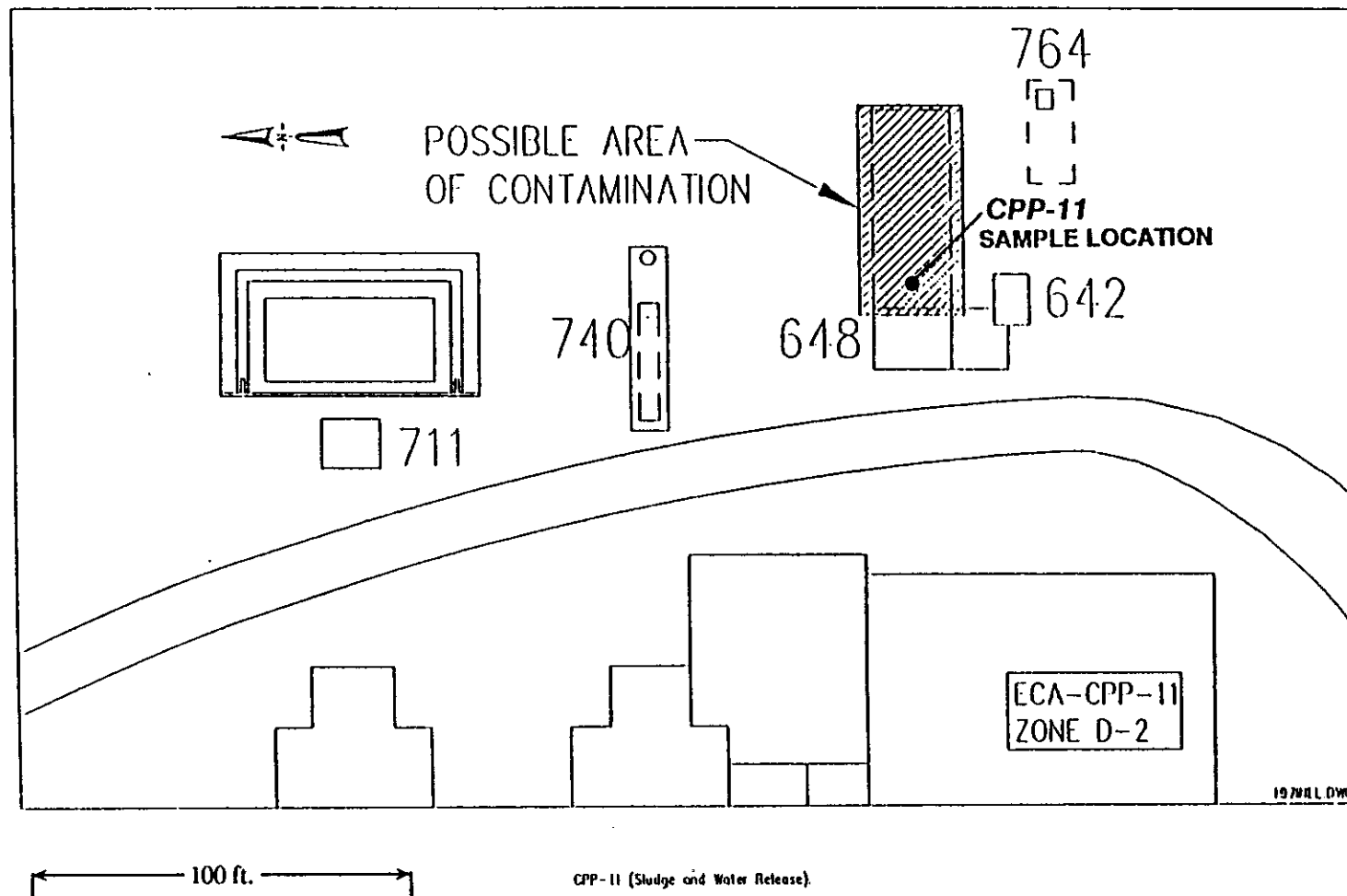


Figure 2-9. Sample location for CPP-11 site.

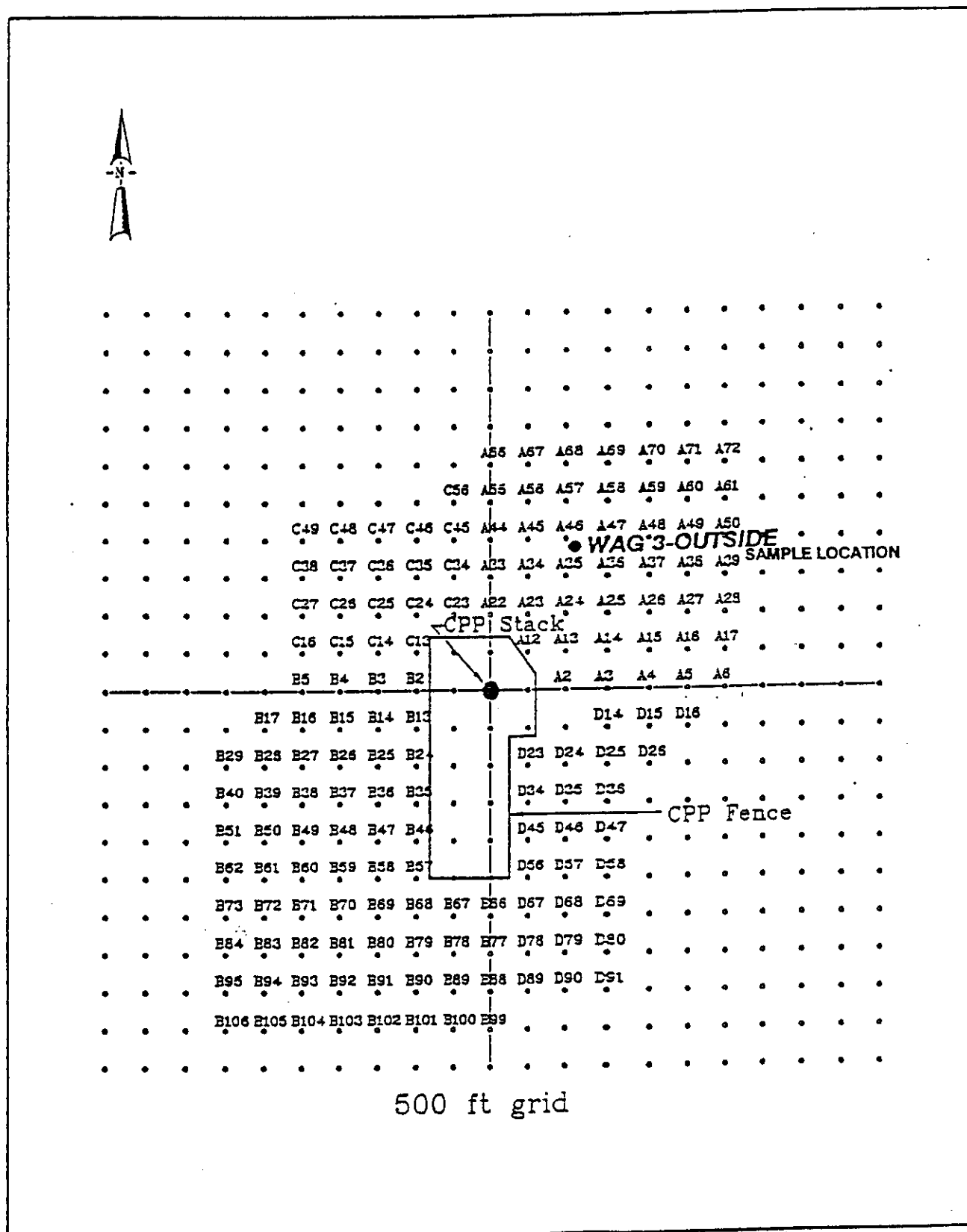


Figure 2-10. Sample location outside WAG-3.



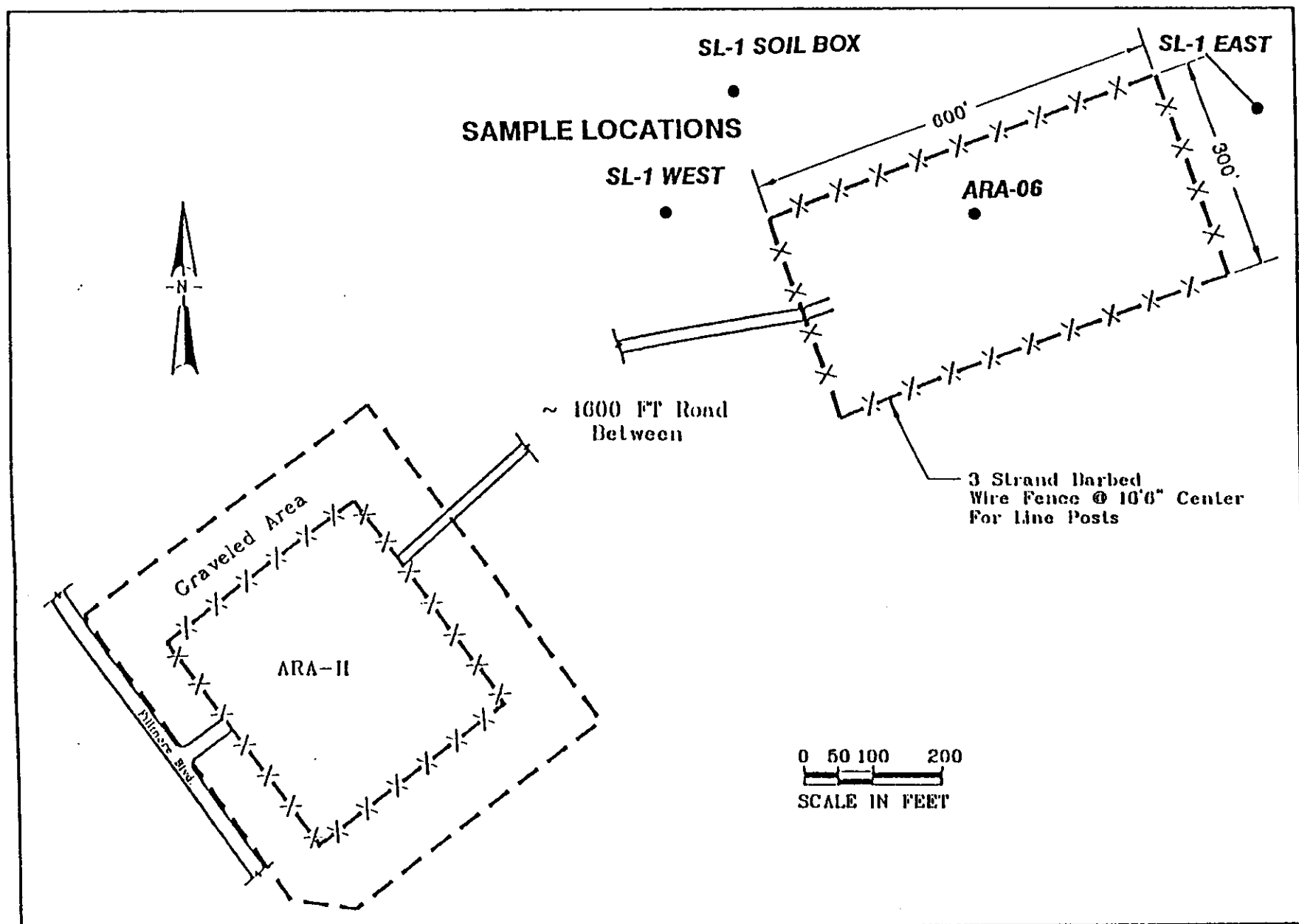


Figure 2-11. Sample locations for the ARA-06 site.

pathway and potential atmospheric dispersion of radionuclides. The surface soils in the SL-1 burial ground area contains a high number of individual radionuclide particles. The surficial contamination is not a product of the buried waste migrating to the surface, but rather separate wastes because of the waste handling process (EG&G 1993d).

Current activities at the SL-1 burial ground include removal of the individual radionuclide particles using portable survey instruments. The current field activities are intended to reduce the number of the radionuclide particles in the surface soils, but removal of contamination below 0.3 m (1 ft) is not being undertaken at this time. Figure 2-11 shows the locations which were sampled at the ARA-06 site.

**2.1.4.2 Site PBF-22, PBF SPERT-IV Leach Pond.** The Special Power Excursion Reactor Test (SPERT)-IV Leach Pond, located at the Power Burst Facility (PBF), lies approximately 33 m (100 ft) south of the contaminated waste holdup tank (Figure 2-12). The pond is surrounded by an obstruction fence approximately 1.4 m (4.5 ft) high, with a personnel gate on the north side approximately 18 m (60 ft) east of the waste holdup tank and a truck entry gate at the southwest corner. The pond was used for contaminated waste effluent from either the reactor building or the waste holdup tank and for chemical waste by-products of the water softener and deionizers. The capacity of the pond was reported to be 428,000 gal, with a percolation rate of 1 in./16 hrs (EG&G 1989).

A 1985 radiological survey was conducted on the leach pond using a Ludlum 2A survey instrument. The probe was held in contact on the outside and inside of the contaminated waste line for 1 minute each. The reading on the outside of the waste line was 200 counts per minute (cpm), while the inside of the waste line showed activity up to 260 cpm. The results of the survey on the leach pond soils did not show the presence of any "hot" spots, as most readings were near or at the background level of 150 cpm. Based on the survey results, two samples were taken near the center of the leach pond. Results of the samples showed Cs-137 concentrations up to 12.5 pCi/g, Sr-90 concentrations up to 5.4 pCi/g, and low levels of Pu-238, Pu-239, Pu-240, americium (Am)-241, U-234, and U-238. Figure 2-12 shows the sampling location for the PBF-22 site.

**2.1.4.3 Sample Location Outside WAG-5.** Areas containing RCS have been previously identified north of the ARA-II facility (ARA-II facility raw RESL data, 1977). Samples taken in an area approximately 76 m (250 ft) due north of the northernmost corner of the ARA-II facility (Figure 2-13) have shown Cs-137 concentrations up to 375 pCi/g. The TS sampling location was determined by radiological field survey and lies to the southeast of ARA-II (Figure 2-13).

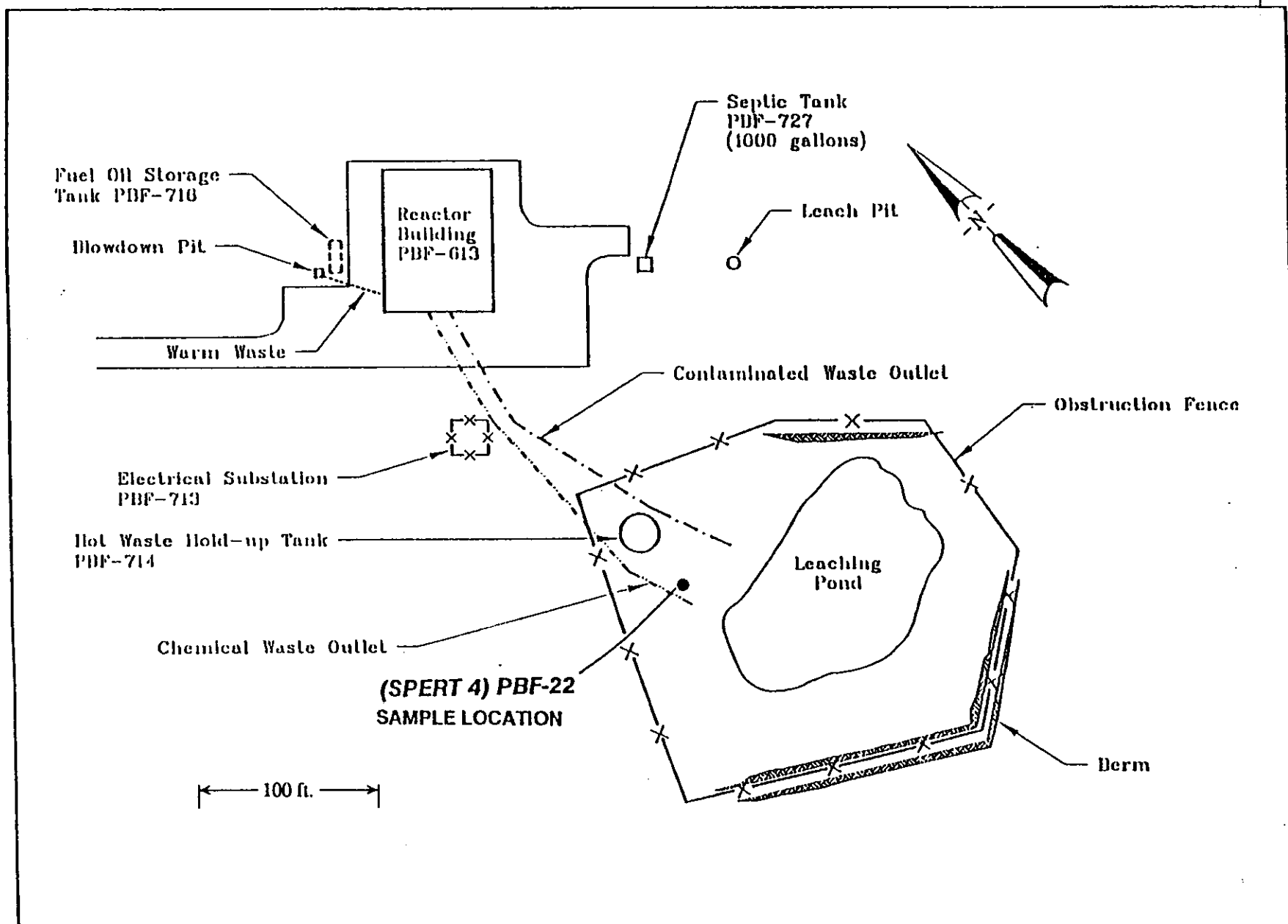


Figure 2-12. Sample location for the PBF-22 site.

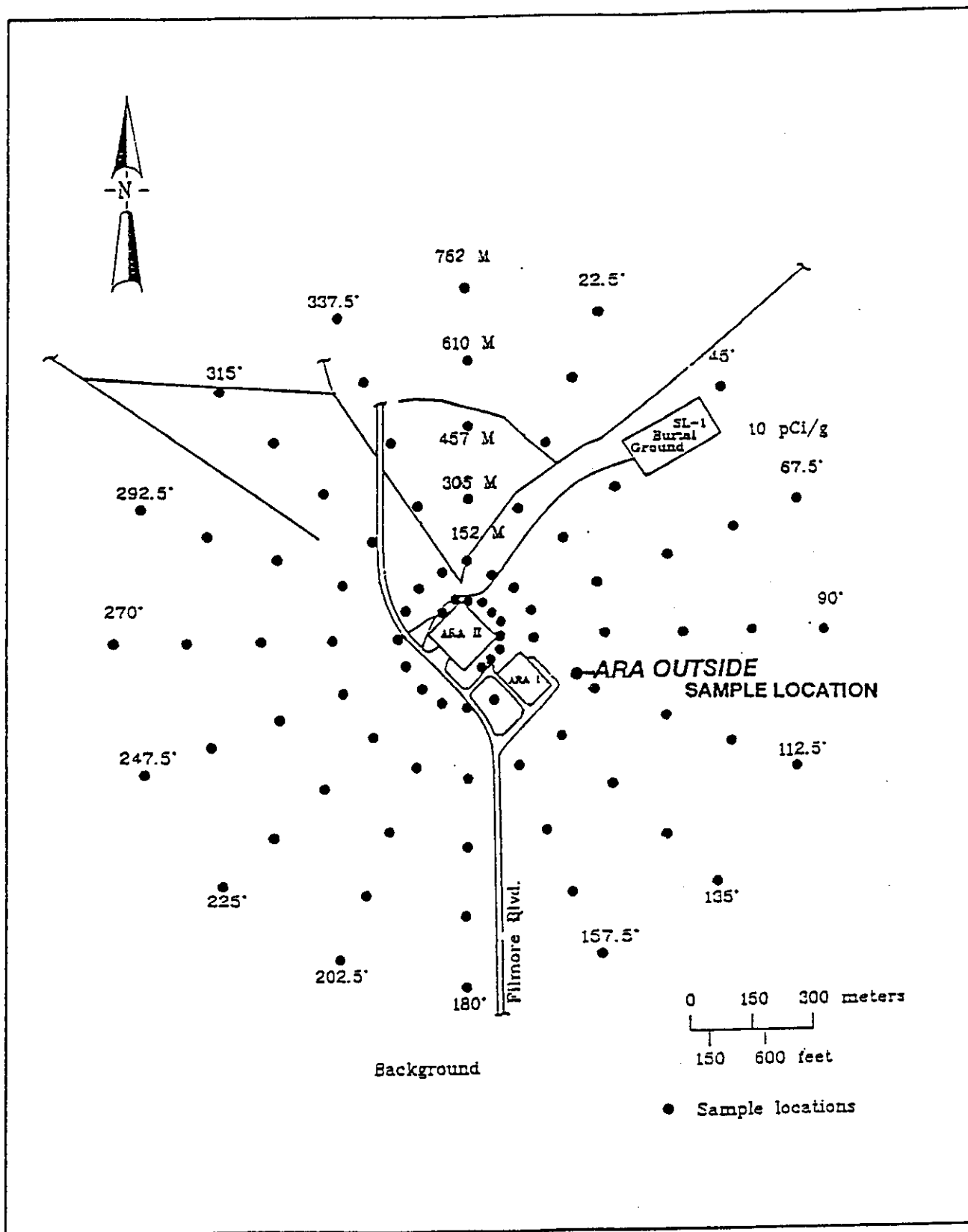


Figure 2-13. Sample location outside ARA.

## 2.1.5 WAG 6 - Experimental Breeder Reactor No. 1

**2.1.5.1 Site BORAX-08, BORAX Ditch.** The site is a radiologically controlled soil area north of the former Boiling Water Reactor Experiment (BORAX) II-V Reactor Facility (Figure 2-14). The BORAX Ditch was recently identified as a new unit and a radiological survey was performed as a result of a Tiger Team finding in May 1992. The ditch contains radionuclide contamination up to 500 cpm, presumably from the BORAX II-V Reactor. The area has been fenced and posted by a Radiological Controls Technician. The location which was sampled for the BORAX-08 site is shown in Figure 2-14 and was determined by radiological field survey.

**2.1.5.2 Site EBR-15, Radioactive Soil Contamination (EBR-1).** Experimental Breeder Reactor (EBR)-15 consists of radiologically contaminated soil in the area of EBR-I (Figure 2-15). The soil contamination is believed to have been caused by a spill in July 1955, of sodium-potassium (NaK) coolant containing various radionuclides, and by a NaK stabilization process used during D&D activities at EBR-I in 1975. The contaminated soil was located in two areas when first detected in 1988. Area 1 was located approximately 70 ft (21 m) west of the EBR-601 Reactor Building and Annex. Area 2 was located approximately 400 ft (133 m) southeast of EBR-601.

Soil samples were collected from both areas from approximately 3 in. bls and analyzed for radionuclides. Both Cs-137 and Sr-90 were detected in these samples. During the excavation of the contaminated soil in Area 1, high winds started spreading the contaminated material to a larger area. Excavation ceased and the area of contamination was surveyed after the project was shut down and designated as Area 3. The excavated contaminated soil from Area 1 was boxed and transported to the RWMC. The boxed soils were returned from the RWMC because the radioactivity was not high enough to meet the RWMC's waste acceptance criteria. The soil returned from RWMC was placed over the clean soil (approximately 4 in.) used to backfill the excavation and then covered with more clean soil in Area 1 only.

A radiation survey of EBR-15 for beta-gamma radiation was conducted in the spring of 1991. Areas exceeding 100 cpm above background levels were flagged and the area was fenced to preclude exposure to contamination. The fence enclosed Areas 1 and 2, as well as a large area of uncontaminated soil. During April 1992, a more detailed radiation survey was conducted within the fenced area to define the current understanding of the extent of contamination. After the contaminated area had been delineated, a surfactant (Wel-don) was sprayed over the soil to reduce further spread of contamination. The contaminated soils cover a combined area of about 66,000 ft<sup>2</sup> within the fenced area. Contamination in most of the area is expected to be confined

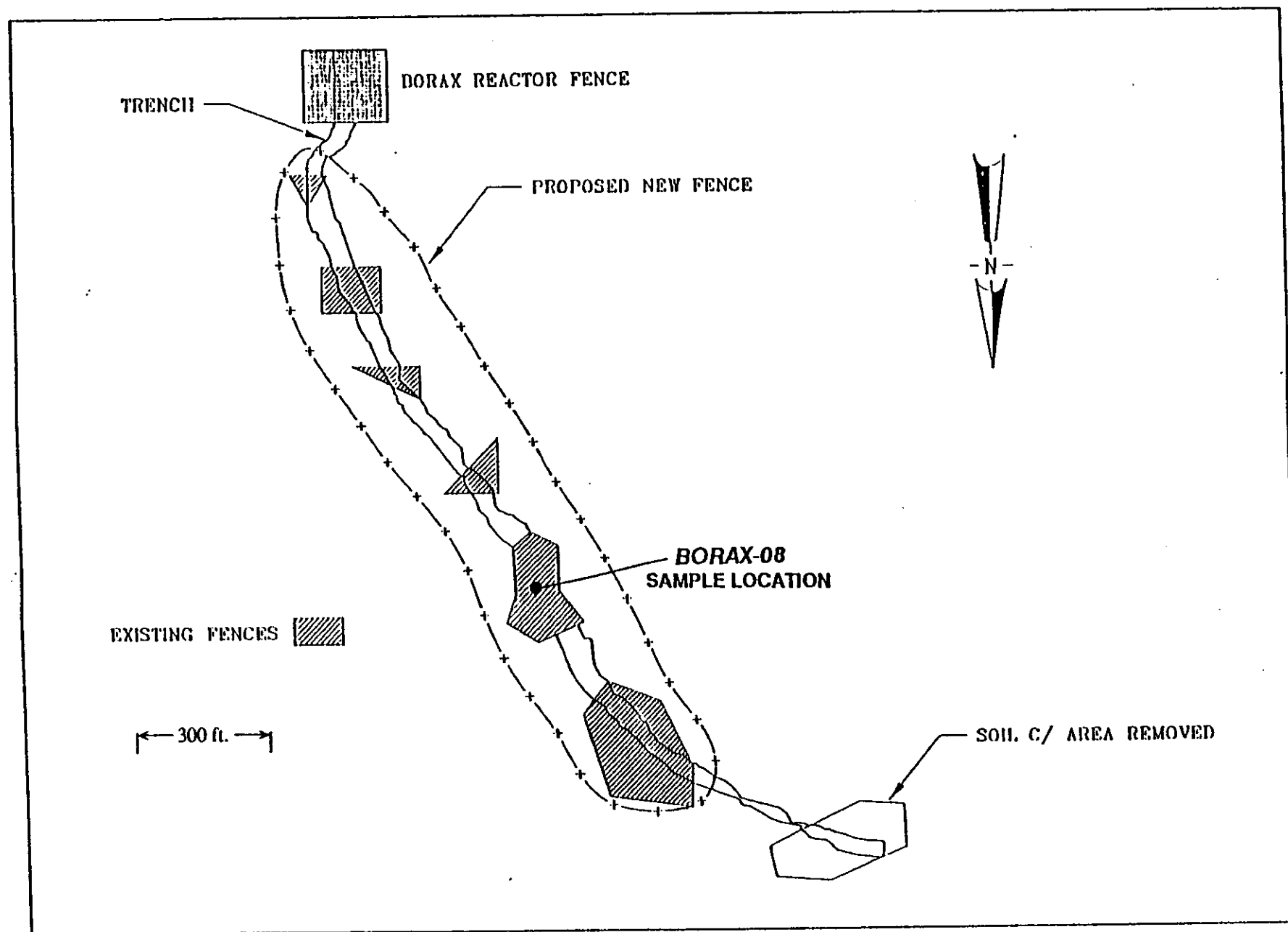


Figure 2-14. Sample location for the BORAX-08 site.

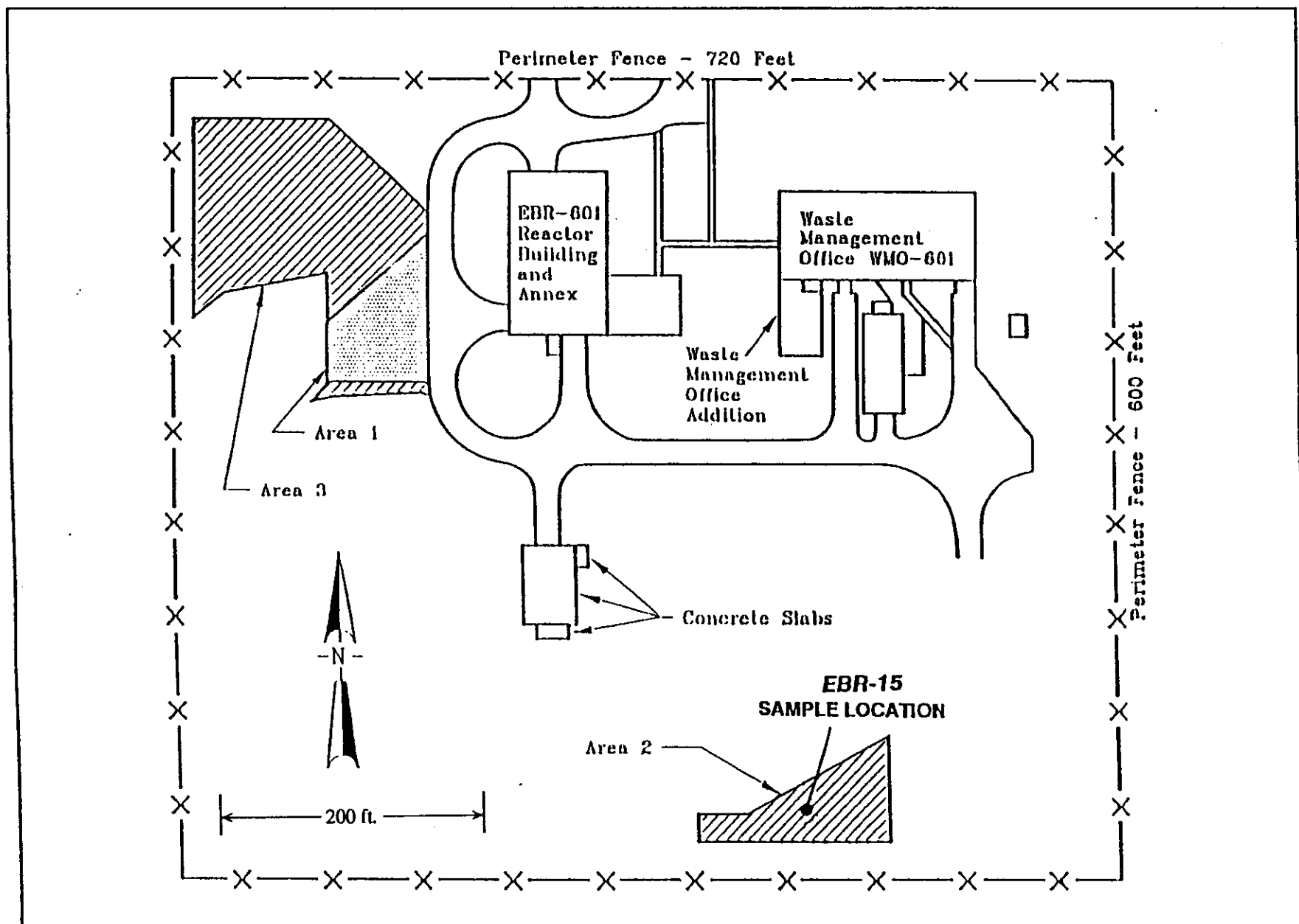


Figure 2-15. Sample location for the EBR-15 site.

to the surface soils; however, in the original area of contamination, the contamination may extend to depths of 3 ft bls or more. The sample location for the EBR-15 site was determined by radiological field survey and is shown in Figure 2-15.

**2.1.5.3 Sample Location Outside WAG-6.** No areas containing RCS outside the BORAX and EBR-I facilities have been previously identified by the RESL sampling efforts; therefore, no surface soils were collected outside the BORAX and EBR-I sites.

## **2.1.6 WAG 7 - Radioactive Waste Management Complex**

**2.1.6.1 OU 7-05, Surficial Water Pathways and Surficial Sediments.** OU 7-05 consists of the drainage and historical ponding areas surrounding the Subsurface Disposal Area (SDA) of the RWMC. The suspected contaminants in this OU are radionuclides that could have migrated to the surficial sediments from the SDA via surface water transport (EG&G 1993e).

The RWMC comprises two major facilities. The SDA is located on the western side of the facility (Figure 2-16) and is comprised of a system of pits and trenches for the burial of radioactive waste. The eastern side of the facility is the Transuranic Storage Area (TSA); an aboveground facility used for storage of transuranic waste, and associated support facilities. The RWMC is located in a low relief area that slopes to the east. With the exception of the east side, the topography of the RWMC is lower in elevation relative to the surrounding topography; consequently, local drainage is inward toward the RWMC and eastward. During 1962, 1969, and 1982, local flooding occurred at the RWMC. During these flooding events, floodwater came into contact with the waste in active burial pits and trenches at the SDA. Inventories indicate that the pits and trenches affected by the local flooding contain radioactive, hazardous, and mixed waste originating from facilities at the INEL. The waste is typically stored in drums and boxes.

Several samples collected during a 1992 sampling effort showed concentrations of radionuclides slightly above detection and/or the 90th percentile for INEL background soils (see Figure 2-16 for previous sample locations). Results of the gamma spectroscopy analysis for the 1992 sampling effort indicated that 50 out of 51 samples were less than the 90th percentile for estimated INEL background soil concentrations for Cs-137 (1.3 pCi/g). Cs-137 was detected at a concentration of 2.23 pCi/g at sample location S21, however, two adjacent samples taken showed concentrations of Cs-137 below background in one sample and a non-detect in the other sample. Results of the alpha spectroscopy analysis for the 1992 sampling effort indicated that 3 of the 51 samples had concentrations greater than detection and/or the 90th percentile for INEL background soils. Results from sample location D2 showed concentrations of Pu-239 at 0.93 pCi/g, and Am-241 and/or Pu-238 at 0.126 pCi/g. Results from sample location S1 showed



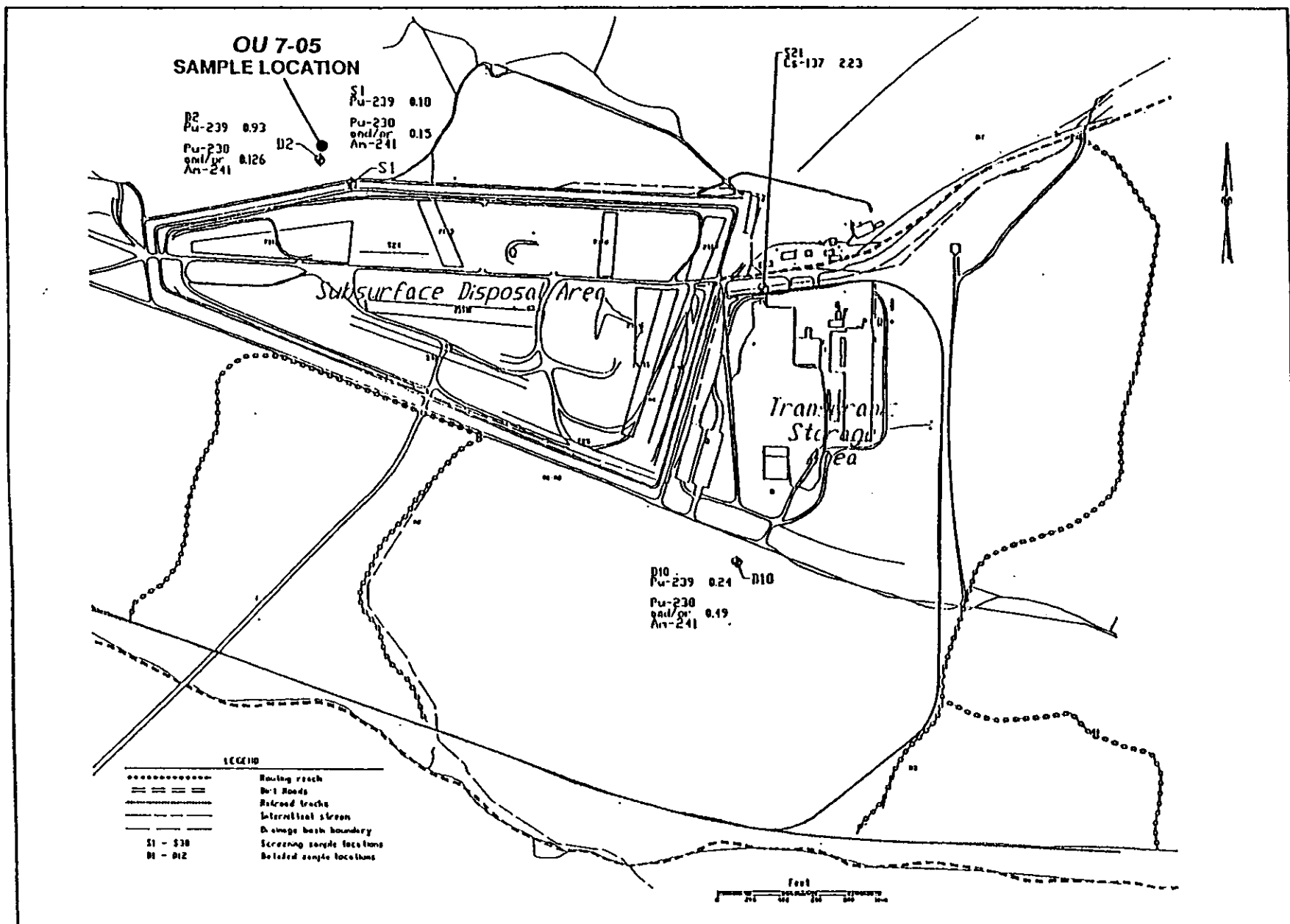


Figure 2-16. Sample location for the OU 7-05 site.

concentrations of Pu-239 at 0.18 pCi/g and Am-241 and/or Pu-238 pCi/g. Finally, results from sample D10 indicated concentrations of Pu-239 at 0.24 pCi/g and Am-241 and/or Pu-238 at 0.49 pCi/g. TS sample collection was performed in the vicinity of the D2 sampling location (Figure 2-16).

**2.1.6.2 Sample Location Outside WAG-7.** Past sampling by the RESL has identified sample location 2-3 north of the TSA at the RWMC as having Cs-137 levels near 2.3 pCi/g (Figure 2-17). Review of the raw RESL data (1985) indicates very few areas of soil outside the RWMC contain radioactivity above background levels. Sample collection for the TS was performed in a location northeast of the RESL 2-3 sample location (Figure 2-17).

## **2.1.7 WAG 9 - Argonne National Laboratory - West**

**2.1.7.1 Stockpile of Rad Soils from Interceptor Canal.** The Argonne National Laboratory-West (ANL-W) interceptor canal extends from Buchanan Blvd. to the ANL-W industrial waste pond, as shown in Figure 2-18. The canal, approximately 1,425 x 30 ft, is used to transport industrial waste from the plant discharge to the industrial waste pond and to carry spring run-off and other natural waters for flood control. The ANL-W interceptor canal was inadvertently contaminated with radioactive liquid waste in October 1969. Contaminated weeds were boxed and taken to the RWMC for disposal. Contaminated soil was removed and stockpiled onto the ground of the INEL outside the ANL-W boundary at the location shown on Figure 2-19. Subsequent sampling efforts indicated the presence of Cs-137, Ce-144, and Co-60 in canal soils. Sampling was performed on soils in the stockpile (Figure 2-19).

**2.1.7.2 Sample Location Outside WAG-9.** No areas outside the ANL-W facility have been identified by the RESL sample collection efforts as having surface soils containing radioactivity above background. Therefore, no surface soil samples were collected outside the ANL-W facilities.

## **2.2 Sample Collection**

Sample collection was performed in accordance with the procedures specified in Barry and Doornbos (1993). Composite surface soil samples were collected with stainless steel hand tools and placed in 20-gal polyethylene containers. For each sampling event, enough sample volume (approximately 10 gallons) was collected to halfway fill a 20-gal polyethylene container. The polyethylene container was then sealed and the contents were mixed for 2 minutes. The samples were then split and transferred into two 5 gallon metal drum containers and shipped to Westinghouse Idaho Nuclear Company (WINCO) for analyses. Soil from each location was also

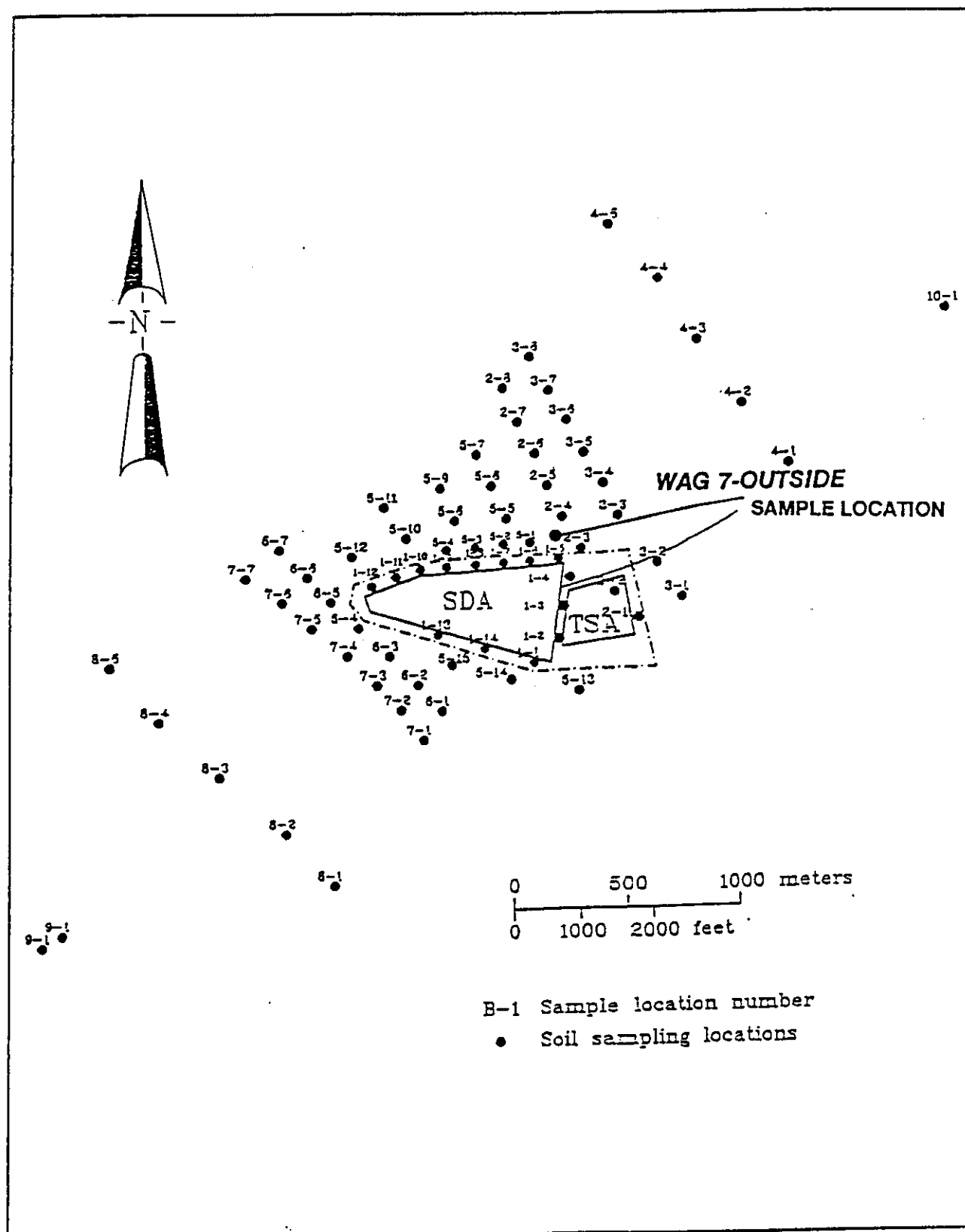


Figure 2-17. Sample location outside WAG-7.

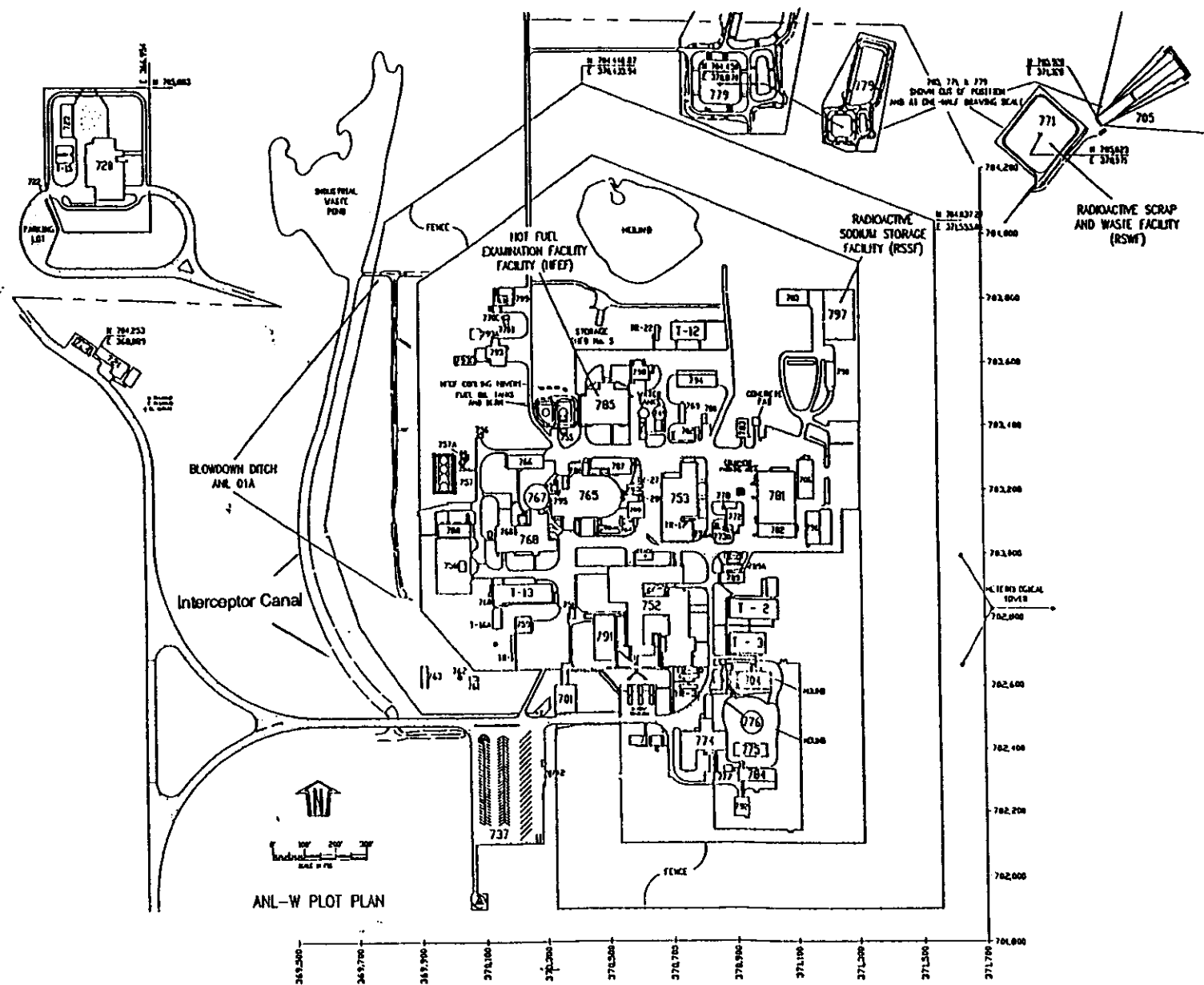
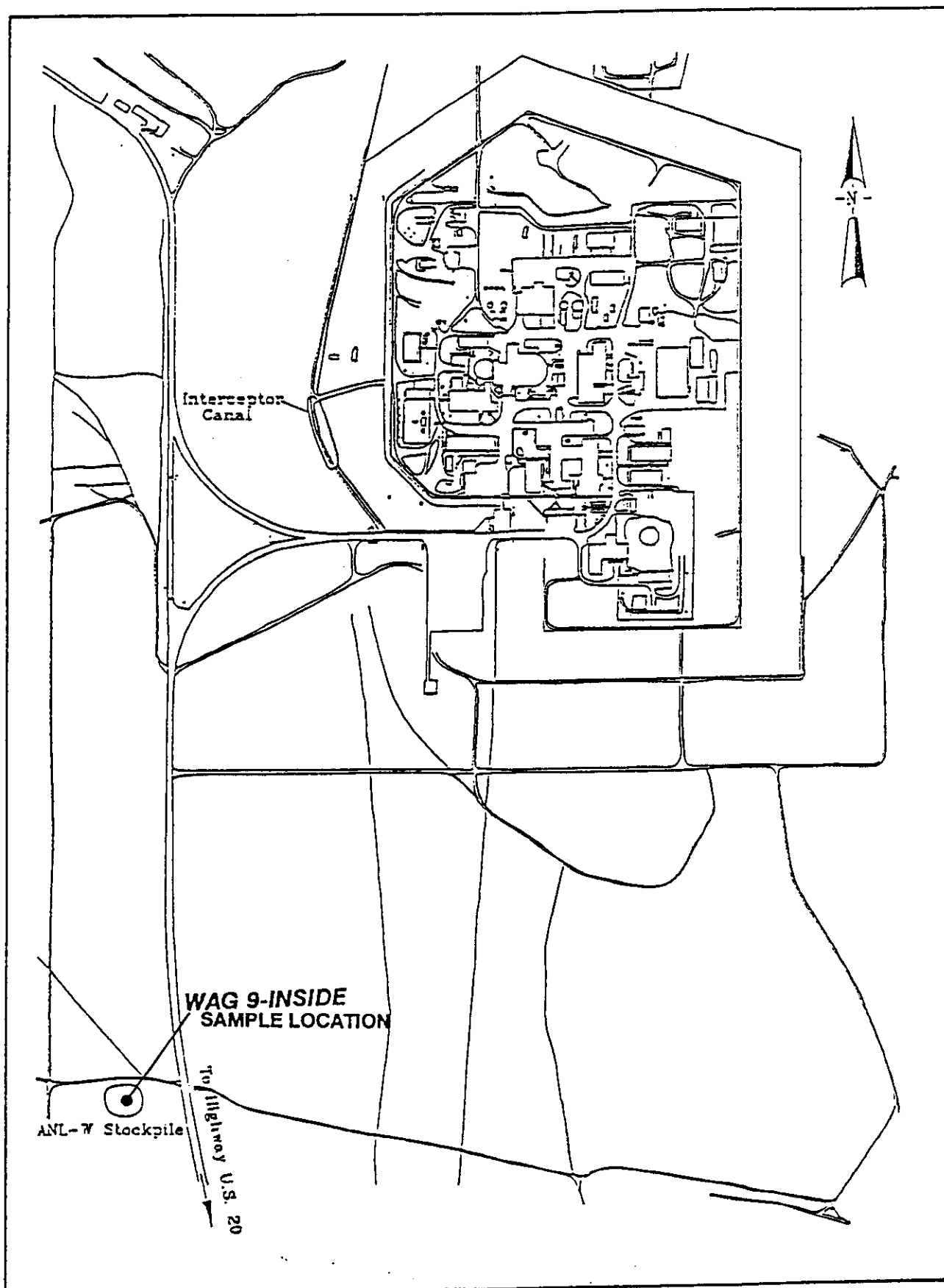


Figure 2-18. Location of ANL-W interceptor canal.



**Figure 2-19.** Sample location for the WAG-9 site.

collected in 16-oz plastic squat jars for analysis at the Radiation Measurements Laboratory (RML) to determine if the sample containers must be handled as radioactive shipments.

### **3.0 LABORATORY ANALYSES**

WINCO personnel performed the laboratory analyses on the field samples. Samples were analyzed for particle size distribution, radionuclide indicators (gross alpha and gross beta), and specific radionuclides. The radionuclide and radionuclide indicator distribution in each particle size fraction was determined. The effects of mechanical attrition on the redistribution of specific radionuclides and radionuclide indicators in each particle size fraction were examined.

#### **3.1 Physical Analyses and Treatment**

The INEL soil samples were analyzed for particle size distribution and subjected to low-energy attrition treatment. Particle size distribution of the samples in terms of weight percent was determined before and after attrition by using wet sieving methods. Mechanical attrition was performed as recommended by EPA's Montgomery, Alabama research laboratory. The following sections contain the procedures used for splitting samples, sieving, and attrition.

##### **3.1.1 Sample Preparation**

To ensure representativeness, sample splitting was performed on the field samples prior to conducting particle size analysis and attrition treatment followed by particle size analysis. The following procedure was used to split the soil samples:

1. Place a short strip of white duct tape on 2 two-liter wide-mouth polybottles, label the tape and obtain tare weights on the polybottles. Write the tare weights on the polybottles as well.
2. Ensure that the collection bins at the bottom of the splitter are in place and that the plastic curtains are in place at the bottom of the splitter and at the front of the hood.
3. Open the 5 gallon drum by unscrewing the bolt which locks the lid. If the lid is locked in place with flanges, bend the flanges up with a screwdriver and pull the lid off when it becomes loose.
4. Pull out the bag which contains the sample and place in the hood where the splitting will be done. If the drum does not contain a sample bag for double containment, the entire drum will have to be placed in the hood. Once that particular drum is emptied of its contents, it will have to be bagged out and discarded as compatible radioactive waste.

5. Cut the bag with a small knife and deliver 5-6 scoop loads of soil into the hopper located at the top of the splitter. Smooth out the pile of soil in the hopper with the scoop before splitting it.
6. Pull the lever slowly and allow the soil to go through the splitter. After this is done, move the rocks around with your hands to allow attached soil and small rocks to fall through the splitter.
7. Place the remaining rocks (approximately  $> 2"$  diameter) which did not go through the splitter into two separate buckets, splitting them by hand as you remove the rocks from the splitter.
8. Continue with Steps 5 through 7 until all of the remaining soil is removed from the original container.
9. Remove the two collection bins from the bottom of the splitter. Place the contents from one bin into a clean  $12" \times 20"$  radiation bag and leave in the hood until the second split is completed. Place the large rocks from one of the buckets into the radiation bag.
10. Place the contents of the second bin into a bucket of sufficient size to contain the split sample and replace the collection back into the base of the splitter.
11. Split the sample which is stored in the bucket mentioned in Step 10 a second time by following Steps 5 through 8. This time, there will be no large rocks to be split by hand since they have already been separated out.
12. Remove the collection bins from the base of the splitter and place the contents of one bin into the  $12" \times 20"$  radiation bag which contains soil from the first split. Place one half of the rocks from the remaining rock collection bucket into the bag as well. Split the rocks in a random manner by hand as you place these rocks into the bag.
13. Seal the bag with yellow duct tape and place a second yellow  $12" \times 20"$  bag around the sample as it is carefully being removed from the hood. Seal this second bag with yellow duct tape and place in the original drum which contained the sample and place the lid over the drum. NOTE: If the original drum did not have secondary containment with a plastic bag containing the soil inside the drum before opening, the original drum will have to be discarded as compatible radioactive waste and a new drum will have to be used which contains proper labeling.



14. Place the original bolt back on the ring which holds the lid in place and tighten it with a wrench or screwdriver. If the lid is to be locked in place with flanges, bend the flanges down with pliers and secure them as tightly as possible.

15. Place the sample barrel in a secured area for storage.

16. Place the contents of the second bin into the hopper of the splitter. Smooth the surface of the soil and split again by slowly pulling the lever. Make sure all of the sample fell through the splitter and remove the collection bins from the splitter base.

17. Place the contents of one collection bin into a labeled and tared 2-liter wide-mouthed polybottle. Place one half of the rocks from the remaining rock collection bucket into this bottle in a manner which allows the rocks to be split by hand as one is making the transfer. Weigh the bottle on a top-loading balance and mark the weight on the white duct tape attached to the bottle.

18. Follow Step 17 for the second collection bin. Place the remaining rocks into this vessel as well, but splitting is no longer necessary. One of the sample bottles will be used in the sieving process. The other sample split will be saved and stored in a cabinet below the north radiobench in the yellow room for the attrition/sieving process.

### **3.1.2 Particle Size Analysis**

Particle size distribution of the samples in terms of weight percent was determined before and after attrition by using wet sieving. Each sample was wet sieved using 4, 10, 40, 100, 200, and 400 mesh sieves. The weight and weight percent of each size fraction (including fines) was then determined. The following procedure was used to perform the wet sieving process:

#### **A. Cleaning of Sieves**

Sieve cleaning is to be done each time sample is removed from the sieves to the petri dishes.

1. Rinse both sides of each sieve with Millipore water.
2. Use the wire brush to scrape both sides of the sieve.

3. Rinse both sides of the sieve screen again and set the sieve down on a clean surface to drip dry.

4. Perform steps 1 through 3 for each sieve to be used.

## **B. Wet Sieving**

1. Add 100 grams of sample to a clean crystallization dish. Add an equal amount of water to the dish to thoroughly wet the sample.

2. Make sure all sieves are in place and in the right order and a crystallization dish marked "FINES" is in place under the drain hose.

3. Slurry the solids in the dish and add to the top sieve on the sieve shaking apparatus. Rinse the residue soil onto the sieve with water.

4. Place the wet head on the shaker and attach the tension bands to the top sides of the sieve head. Make sure the tension clamps are screwed on as tightly as possible.

5. Make sure the 1 L water bottle that supplies water to the sieve shaker is full. The interval setting should be set at minimum and the amplitude should be set at maximum setting.

6. Turn on the sieve shaker by setting the time for at least 5 minutes. Turn on the peristaltic pump simultaneously. Let the pump run for 15 seconds and then turn it off. (The peristaltic pump is to be run in REVERSE operation).

7. Allow the sieve shaker to run for 30 seconds after the peristaltic pump is shut down.

8. Turn off the shaker by turning timer to the 0 setting. Remove the tension bands by loosening the screw clamps and remove the sieve head. Turn on the shaker and allow the shaker to remain on for ten to fifteen seconds.

9. Turn off the shaker again and lift up the top sieve and rinse water through the sieve, allowing water to drain to the next sieve. Break any clumps of soil with water. Note: if any sieves stick together, rinse and wipe off the lip of the sieve.

10. Repeat rinsing process with each successive sieve on the shaker, making sure the water runs through each sieve.
11. Repeat steps 2 through 10 twice more to ensure clean soil fractions.
12. Remove each successive sieve from the system and rinse the soil fractions into the appropriately labeled (40 mesh, 100 mesh, etc.) crystallization dishes.
13. Go to part A. to clean each sieve before more sample is to be added to the system.
14. When sieves are clean and reorganized, follow part B again. Follow parts A and B successively until all of the sample is processed.

The wet sieving procedure used in this study necessarily differs somewhat from the ASTM standard test method for particle size analysis of soils (ASTM-D422-63). ASTM-D422-63 provides for quantitative determination of particle sizes less than 75  $\mu\text{m}$  (No. 200 sieve) by hydrometer measurement. For the TS investigation quantification of very small particle size was unnecessary; therefore, particle size was quantified down to 38  $\mu\text{m}$  (No. 400 sieve) and particle sizes less than 38  $\mu\text{m}$  were grouped as "fines". ASTM-D422-63 does not require wet sieving; however, wetting of sample material was necessary for entrapment of radionuclides to ensure radiation protection. ASTM-D422-63 does not require use of an automated shaker system; however, an automated shaker was used in the analysis to simplify the process and ensure uniformity of method.

### **C. Handling of Fines and Rinse Water**

1. Transfer "fines" slurry water from the glass crystallization dish to a 4L jug which is labeled "Fines Slurry H<sub>2</sub>O".
2. Transfer some of slurry water to 250 mL wide mouth centrifuge polybottles. Cap the polybottles, wipe them clean with windex and terri towels, and transfer the vessels to a top loading balance.
3. Weigh each bottle to balance out the load of each bottle for the centrifuge. if the weight of the opposing bottle is different by more than 1.0 gram, use an eyedropper to transfer some of the contents from the heavier bottle to the lighter bottle until the weights agree to within 1.0 gram.

4. Place the balanced bottles into the sample holders of the centrifuge system and then cap them with the clear plastic lids and seal them by putting the retaining straps in place.
5. Place the sealed samples into the centrifuge system and close the lid. Make sure the balanced containers are opposing (across from) each other on the centrifuge. Set the time for 15 minutes and the rotation speed for 3600 revolutions per minute. Turn on the system by pushing the start button at the bottom right corner of the machine.
6. After the centrifuge has completed its run time, open the lid and remove the bottles from the sample containers. Transfer the bottles back to the hood and pour all but 4-5 mL of the supernate into a labeled 4 L "Supernate Water" jug.
7. Continue with steps 1 through 6 until the fines slurry has been centrifuged.
8. Transfer the contents of the "Supernate Water" jug into a crystallization dish labeled "Water Wash". The crystallization dish is to be placed onto a large hot plate such as a Corning PC-100 and set at a temperature setting of 4.8. Evaporate the liquid to about 500 mL in order to leave room for rinsing out the dish when the liquid is transferred.
9. Transfer the partially evaporated liquid to a labeled 1 L polybottle.
10. Dilute liquid in bottle to form 1 L of solution.
11. Seal the 1 L polybottle and check the bottle for external radioactive contamination.
12. Transfer the 1 L polybottle to Radiochemistry for analysis.

### **3.1.3 Particle Attrition**

Mechanical attrition (vigorous washing) was performed on the samples. Attrition was added to the tests being conducted during conversations with the EPA's Montgomery, Alabama Research Laboratory. It was decided, partly on there test work on Warm Waste Ponds samples, that this would be a possible treatment method worth considering and testing. The method used is described below.

## **A. Summary of Method**

An aliquot of the soil to be tested ranging in size from 250 grams to 375 grams is placed in a 4 liter wide-mouth polybottle. The sample is mixed with a known amount of deionized water to produce a specified liquid-to-solid (L/S) ratio. The sample is placed on an orbital shaker and set for a predetermined speed for a specific length of time. The shaking process causes the soil particles to abrade each other which allows more complete separation in the next phase of soil treatment.

## **B. Apparatus and Materials**

Orbital shaker with tachometer, modified to hold 12 4-Liter containers. The shaker also contains a built in timer with an automatic stopping system.

Balance, table-top model capable of weighing up to 3000 grams, 4-Liter plastic containers, Nalgene or equivalent, 1000 ml polybottles, disposable eyedroppers, and stainless steel scoop.

## **C. Reagents**

Deionized water

## **D. Safety Procedures**

All personnel are required to wear protective clothing. The minimum required clothing includes green scrubs, yellow lab coat, safety shoes, safety glasses, shoe covers or launderable rubber boots, and yellow latex gloves. If one is working in the hood or radiobench, then long yellow plastic gloves and yellow latex gloves are also required.

Dry samples will be handled in the hood as much as possible due to the possibility of airborne contamination.

## **E. Soil Washing Procedure**

1. Obtain the sample from the storage cabinet and determine the amount of sample to be sieved. The sample should be in a 2 liter polybottle.

2. Obtain a clean stainless steel deep pan and place it in the hood on top of moistened terri towels. Transfer the sample from the polybottle to the deep pan inside the hood.
3. Carefully wipe the outside and top edges of the pan with terri towels moistened with Windex or similar cleaner. Then transfer the stainless steel pan to a bench top covered with moistened terri towels.
4. Label an appropriate number of 4 liter wide mouth polybottles which are fully clean. Place one of the bottles on the table top balance and tare out the weight of the bottle.
5. With a clean stainless steel scoop, transfer a minimum of 250.0 grams of soil into the bottle. Make sure the weight does not go beyond 375 grams since complete washing may be hampered by space constraints inside the bottle.
6. Follow steps 4 and 5 until all of the designated soil sample has been placed in 4 liter bottles.
7. Add deionized water to each polybottle following a liquid to solid ratio of 4 to 1 by weight. Weigh to the nearest tenth of a gram.
8. Place all of the sample bottles on the orbital shaker and balance them for weight distribution.
9. Set the RPM on the orbital shaker for 200 RPM and the time for 0.8 hr. Turn on the orbital shaker and make sure the time-set LED is on. Also, make sure the RPM LED read-out is showing 200.
10. After 48 minutes have transpired, the system will automatically turn off and a beeping sound will become audible. Press any button on the front of the instrument and the beeping tone will end.
11. The samples are now ready to be transferred to the hood where sieving is to take place.

## **3.2 Radiological Measurements**

WINCO personnel performed gamma spectrometry, gross alpha, and gross beta measurements on the sieved as-received and the sieved attrited samples. This section summarizes the measurement procedures which were used.

### **3.2.1 Gamma Spectrometry**

The WINCO procedure for performing gamma spectrometry analyses is summarized in this section. The specific details of the procedure are provided in "Operating Instructions for the Data General Eclipse S/140 Dedicated Computer Gamma Spectrometry", Method 3993, Gamma-Scan-2, Rev. 3, January 1991.

#### **A. Apparatus**

The basic apparatus used in performing gamma spectrometry measurements consists of shielded germanium diode detectors with a Data General Eclipse S/140 computer, Tektronix 4207 graphic interactive terminals, Tektronic 4695 terminal plotter/printer, Data General dasher D100 system terminal, and Data General dasher TP2 live printer. The system is equipped with an automatic sample changer and controller. The WINCO laboratory uses two dedicated computer gamma spectrometry systems named A1 and A2. Each system is capable of running four or more detectors simultaneously. Each detector is operated independently.

#### **B. Determination of Background**

Background determination is to be performed for all operating detectors on each system at least once a week. The counting times should be overnight (15 hours) or over a weekend (50 hours). Shorter backgrounds may be used if an emergency situation requires it. These backgrounds are calculated and entered into a QCBKG file in the computer.

#### **C. Instrument Calibration**

Each detector must be calibrated using standards obtained from the National Institute of Standards and Technology (NIST) or standards traceable to NIST. The standards used for calibration are mixed nuclide sources covering the desired energy range of approximately 0.08 to 2 MeV. Various geometries are calibrated to cover a wide variety of emission rates and sample configurations. Efficiencies are calculated for each nuclide

in the mixed standard and for each geometry calibrated using the computer program PLOTEFF. Additional information can be found in the following WINCO documents: Analytical Chemistry Methods Manual (ACMM), Volume II, Calib-Photon-1, Method 2-0015 (3986) and Users Guide to the ICPP Improved Gamma Spectra Acquisition and Analysis System, J. M. Gross, Rev. 2, April 1988.

Europium-152 Standard Reference Material (SRM) Standards (either obtained directly from NIST or traceable to NIST) are used to determine if systems A1 and A2 are in calibration. These check sources are counted daily on each detector at 10 cm (called geometry 10). The d/s/spi values obtained for the energies 122, 245, 344, 779, 964, 1112, and 1408 keV are entered (and saved) in the Qual Com program file if they pass the three sigma test in the program. If they don't pass, it is recommended that they be rejected by the operator. If a detector fails the daily serviceability test, no samples are to be analyzed on it until the problem has been resolved.

#### **D. Instrument Maintenance**

Maintenance shall be performed on the various system components when required and when recommended by vendor manuals. See instruction manuals supplied by system component vendors.

#### **E. Sample Preparation**

Sample preparation methods which are used are given in WINCO's ACMM, Volume II. Sample-Prep-1, Method 2-0012 (3981); Sample-Prep-2, Method 2-0013 (3982); and Sample-Prep-3, Method 2-0014 (3983).

For this investigation samples were prepared in 40 dram (148 ml) plastic vials. To eliminate self shielding and potential geometry problems all +4 ( $> 4.75$  mm) and +10 ( $\leq 4.75$  and  $> 2$  mm) size fractions were crushed prior to gamma spectrometry measurements. All samples were desiccated prior to gamma spectrometry measurements.

Standard operating procedures for handling of radioactive samples must be followed: SOPs R.1.32 "Laboratory Safety in the Analytical Chemistry Laboratories" and R.1.34 "Handling Radioactive Material in Analytical Chemistry Laboratories", Procedure 3.1 through 3.27.



## **F. Sample Measurement**

Gamma spectrometry analysis is performed on samples in accordance with the Users Guide to the ICPP Improved Gamma Spectra Acquisition and Analysis System by J. M. Gross, Rev. 2, April 1988, and the Data General Users Manual 093-000122-05. Calculations are detailed in Users Guide to the ICPP Improved Gamma Spectra Acquisition and Analysis System by J. M. Gross, Rev. 2, April 1988. For this investigation gamma spectra were measured on the samples for 1 hour.

### **3.2.2 Gross Alpha and Gross Beta**

Gross alpha and gross beta measurements were made by preparing a liquid extract of the solid sample and then using EPA method 9310 "Gross Alpha and Gross Beta" to perform the measurement. EPA method 9310 is intended to provide a rapid screening measurement of groundwater and surface water samples to indicate whether specific analyses are required (EPA 1986). The sample preparation differed from that of EPA method 9310 in that it involved leaching sediment samples in  $\text{HNO}_3$  and  $\text{HCl}$ , converting the leachate to the  $\text{NO}_3$  form, making up to a known volume, and quantitatively transferring a portion of the sample to a planchet for counting. In EPA method 9310 no leachate preparation is required; the sample matrix is simply groundwater or surface water which is then evaporated into a small volume and subsequently transferred quantitatively to the planchet for counting. In both cases the sample portion on the planchet is evaporated prior to counting. EPA method 9310 requires the use of either proportional counting system or a scintillation detection system. The WINCO lab used a proportional counting system to perform the gross alpha and gross beta measurements. Details of the sample preparation procedure are provided below.

#### **Preparation of Samples for Gross Alpha and Gross Beta Measurements**

1. Weigh  $1.0 \pm 0.2$  g of soil into a 50-mL centrifuge tube. Larger or smaller amounts of soil samples may be used depending upon the amount of dissolved solids in the final leachate.
2. Record the weight ( $\pm 0.01$  g) of the sample on the Gross Beta/Gross Alpha Analysis Work Sheet.
3. Add  $20 \pm 4$  mL of 8M nitric acid to the tube.

4. While heating the tube in a hot water bath ( $>80^{\circ}\text{C}$ ) for 15 to 20 minutes, occasionally swirl the contents of the tube. This will leach the predominant radionuclides from the soil.
5. Centrifuge the tube for  $10 \pm 2$  minutes to separate the soil from the leachate solution.
6. Pour the supernate into a 250-mL Erlenmeyer flask.
7. Repeat Steps 3 through 6 one time. This step is performed once.
8. Add  $20 \pm 4$  mL of 6M hydrochloric acid to the tube.
9. While heating the tube in a hot water bath ( $>80^{\circ}\text{C}$ ) for 15 to 20 minutes, occasionally swirl the contents of the tube. This will leach radionuclides from the soil.
10. Centrifuge the tube for  $10 \pm 2$  minutes to separate the soil from the leachate solution.
11. Pour the supernate into the same 250-mL Erlenmeyer flask.
12. Repeat Steps 8 through 11 one time. This step is performed once.

**CAUTION:** Evaporating the leachate will form corrosive nitrosyl chloride vapors and should only be performed in an operating hood. Handling of the flask while evaporating the solution should be done while wearing plastic or rubber gloves and a laboratory coat.

13. Evaporate the leachate in the flask to near dryness on a hot plate. Nitrosyl chloride vapors from aqua regia are formed during the evaporation.
14. Add 15 mL of concentrated  $\text{HNO}_3$ .
15. Evaporate the solution to dryness. This removes residual chlorides via evaporation of  $\text{HCl}$ .
16. Repeat Steps 14 through 16 once.
17. Cool the container to room temperature.

18. Add  $5 \pm 2$  mL of 4M  $\text{HNO}_3$  to the flask.
19. Warm the container gently.
20. While the dissolution matrix is warm, use 4M  $\text{HNO}_3$  rinses to quantitatively transfer the dissolution matrix solution to a 50-mL or 100-mL volumetric flask. The size of the flask is dependent upon the amount of dissolved solids present in the dissolution matrix. A quantitative transfer should include at least three rinses of the dissolution container.
21. Cool the flask to room temperature.
22. Bring the solution to the appropriate volume in the volumetric flask with water.
23. Record the volume of the solution on the Gross Beta/Gross Alpha Analysis Work Sheet.
24. Pipe 1-2 mL onto a planchet. Add enough water to make final volume 5 mLs.
25. Evaporate under a heat lamp until dry.
26. Allow to cool and record final weight of planchet on Gross Alpha-Beta Worksheet.
27. Transfer samples to counting room to be counted on Alpha/Beta proportional counter.

## 4.0 RESULTS

Two soil samples from each of 21 sites were split by wet sieving into +4, -4+10, -10+40, -40+100, -100+200, -200+400, and -400 (fines) size fractions (Table 4-1). Each fraction was then measured for gross alpha, gross beta, and gamma contamination. One sample was split in its as-received condition, and the other was pretreated using a vigorous washing procedure supplied by the EPA. This procedure involves shaking a slurry of soil which induces a mild abrasion (attrition) to enhance the separation of fine particulate from the more coarse grains. The data discussed in this section are summarized in tabular form in Appendix A.

### 4.1 Particle Size Analysis

Particle size distribution as weight percent was determined for the as-received and attrited samples. The complete results are given tabular form in Appendix A.

A correlation is expected between the soil type and particle size distribution. The sample results can be grouped on the basis of the four general soil types present at the WAGs which were sampled (Table 4-2). Plots of cumulative weight percent and particle size were made for the as-received samples and are grouped by the four general soil types shown in Table 4-2 (Figures 4-1 through 4-4). Particle size distribution data for as-received samples show similarities within each of the four general soil types (Figures 4-1 through 4-4). With the exception of the data from WAG-1 which has no general soil type counterpart, notable similarities are exhibited in the particle size data between WAGs within each group. The data may suggest that soil type may be a key factor to be considered in the design of future sampling and analysis efforts. It is imperative to note that the data are single samples representing a given type location, and provide no knowledge of variation in each sample population. Additional, more detailed information may need to be collected on soil types at each RCS site being considered.

As in natural systems, a correlation might also be expected between the mode of deposition and particle size distribution at each sample location. For example wind-deposited sediment should have a relatively high proportion of finer grained sediment than sediment deposited by running water. Detailed information on the specific mechanisms of deposition for each sample location is not available; however, the possible correlation of particle size distribution and postulated mode of deposition was examined. Table 4-3 gives the postulated mode of deposition for each sample location. As can be seen, the three mechanisms represented are: 1) aqueous deposition of dissolved species by surface spills, leaks and discharges, 2) airborne distribution of fine particulate, and 3) physical distribution by artificial means or gross

**Table 4-1. Sieve number and corresponding particle size range.**

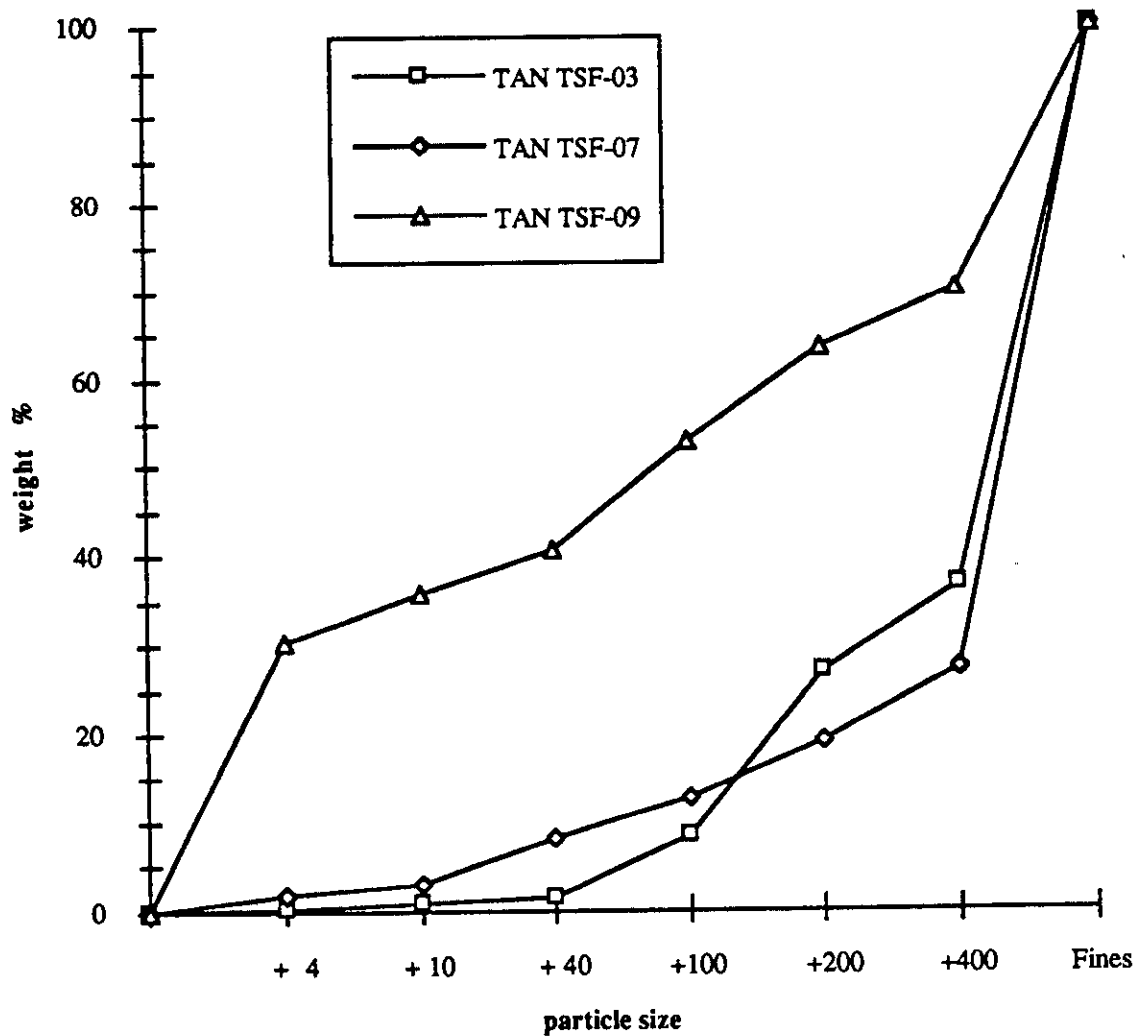
<b>Sieve Number</b>	<b>Particle Size Range (mm)</b>
4	> 4.75
10	≤ 4.75 and > 2
40	≤ 2 and > 0.425
100	≤ 0.425 and > 0.15
200	≤ 0.15 and > 0.075
400 <sup>a</sup>	≤ 0.075 and > 0.038

a. Fines pass through the #400 sieve and are therefore ≤ 0.038 mm in size.

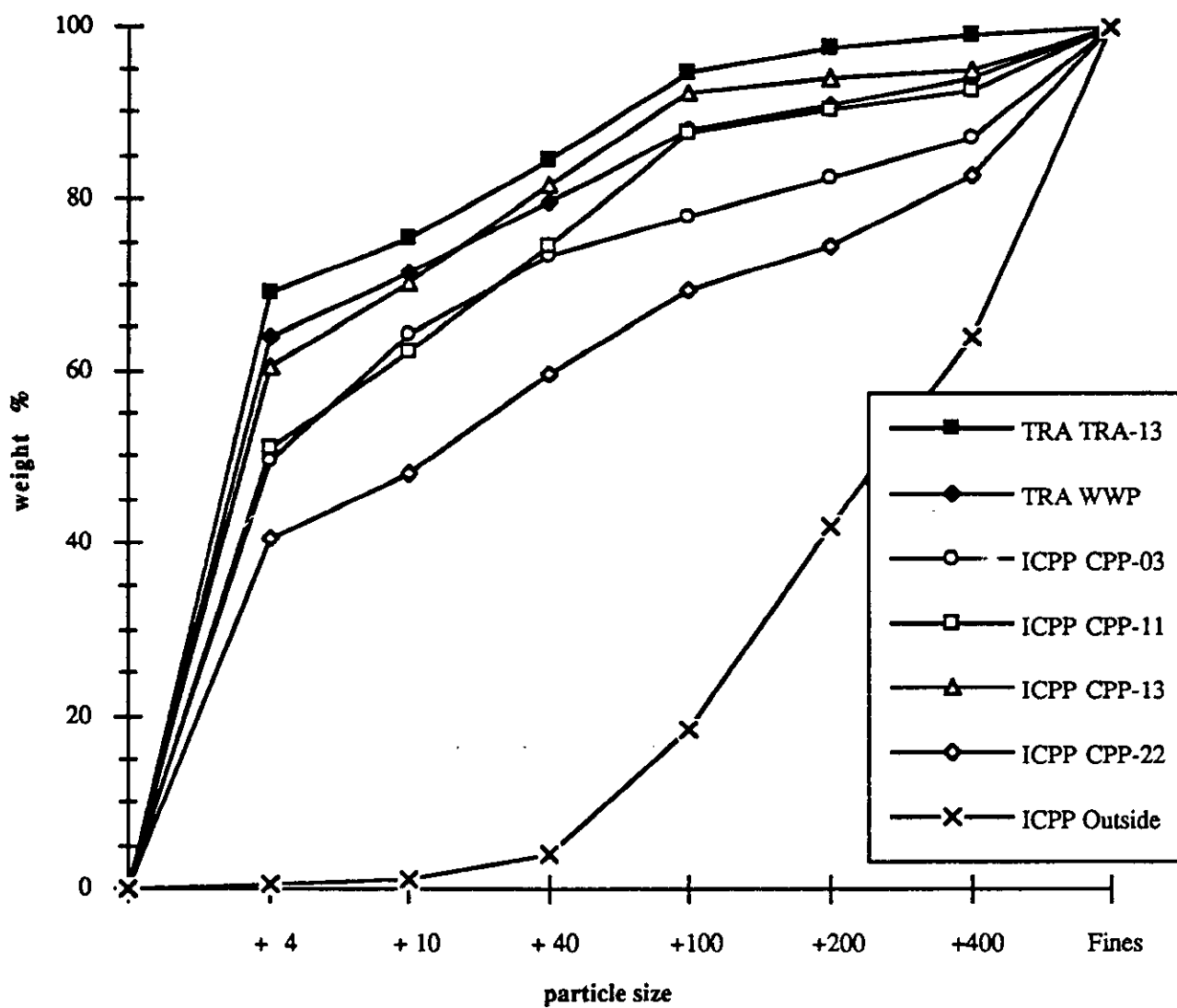
**Table 4-2. WAGs grouped on the basis of general soil type.**

<b>Group</b>	<b>WAG</b>	<b>General Soil Type<sup>a</sup></b>
1	1 (TAN)	Deep, alkaline, fine-grained lacustrine sediments from the ancestral Lake Terreton, overlain in some areas with sand dunes.
2	2 (TRA) 3 (ICPP)	Shallow to deep (<20" to >60") medium- to coarse-textured soils over gravel; derived from alluvial deposits of the Big Lost River and Birch Creek.
3	5 (PBF) 9 (ANL-W)	Shallow to deep (<20" to >60") moderately coarse-textured soils (from eolian sand) on basalt plains with slope ranges from 0 to 20%.
4	6 (EBR-1) 7 (RWMC)	Shallow to deep (<20" to >60") medium to fine grained soils (from loess) on basalt plains with slope ranges from 0 to 30%.

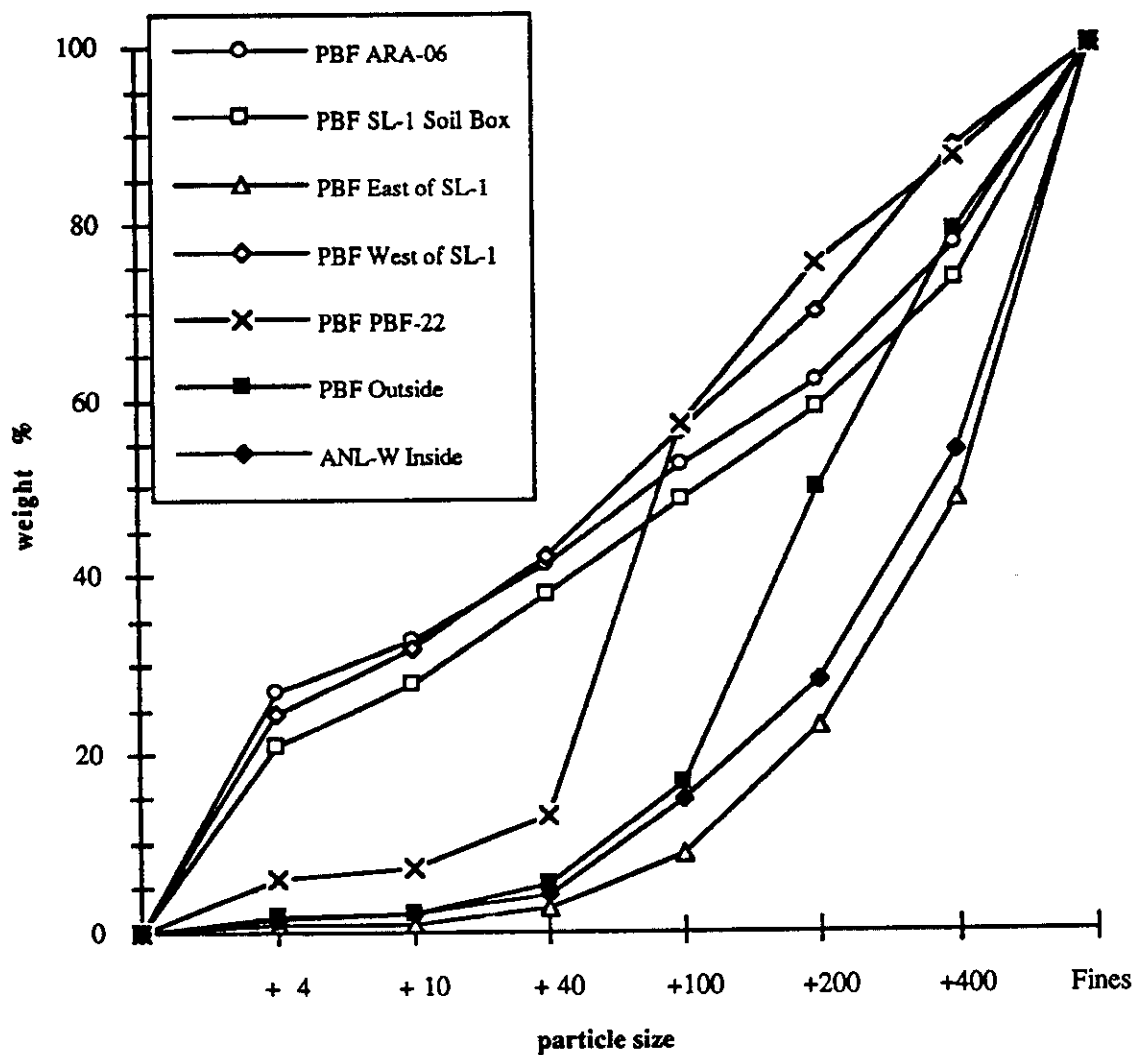
a. General soil types are from unpublished data of Olson, G. L., and D. J. Jeppesen, 1993, Draft, *Soils of the Idaho National Engineering Laboratory*, EGG-CEMA-10641, January.



**Figure 4-1.** Particle size distribution as cumulative weight percent for the WAG-1 (TAN) as-received samples.

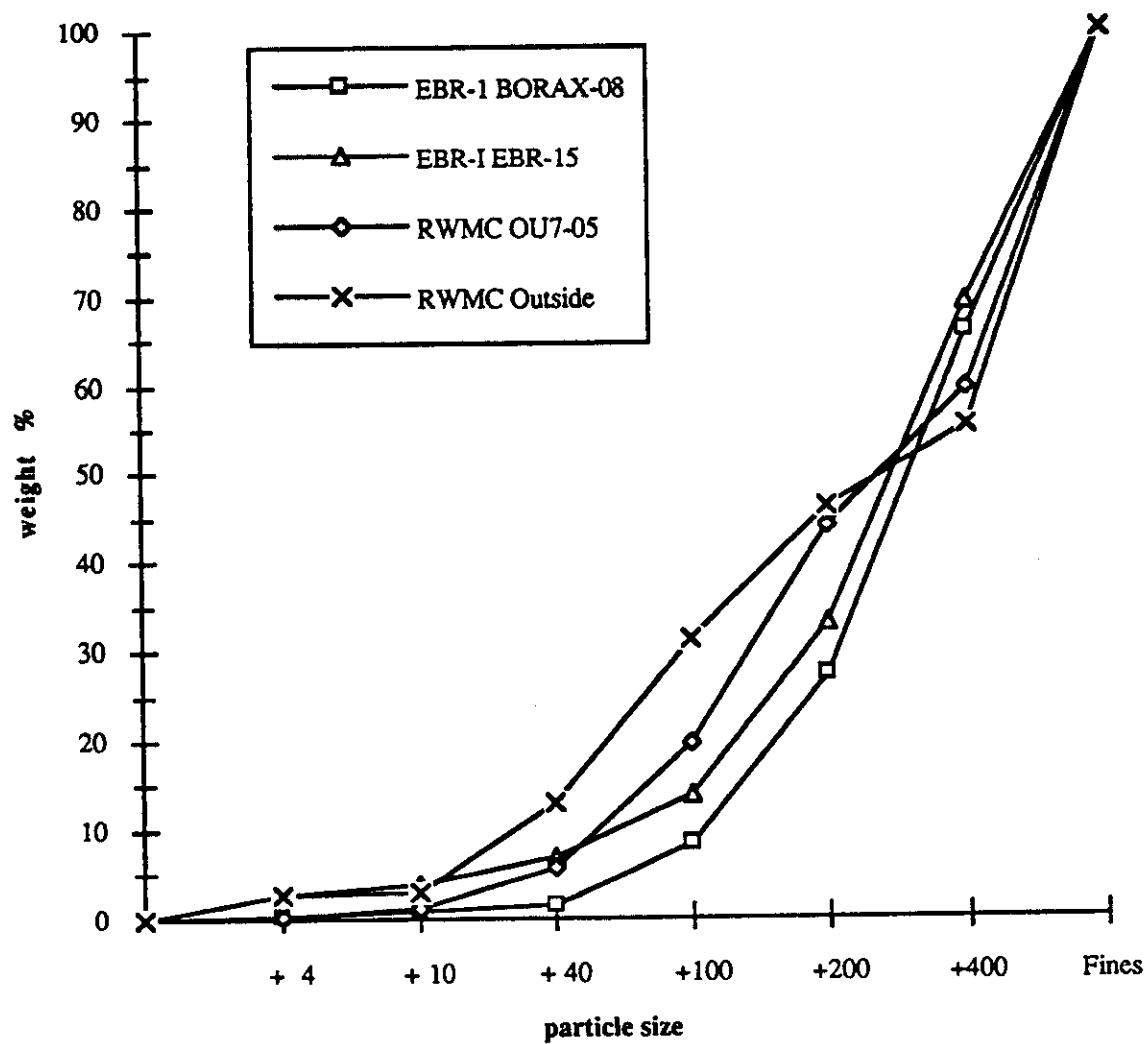


**Figure 4-2.** Particle size distribution as cumulative weight percent for the WAG-2 (TRA) and WAG-3 (ICPP) as-received samples.



**Figure 4-3.** Particle size distribution as cumulative weight percent for the WAG-5 (PBF) and WAG-9 (ANL-W) as-received samples.





**Figure 4-4.** Particle size distribution as cumulative weight percent for the WAG-6 (EBR-1) and WAG-7 (RWMC) as-received samples.

**Table 4-3. Postulated mode of deposition for sample locations.**

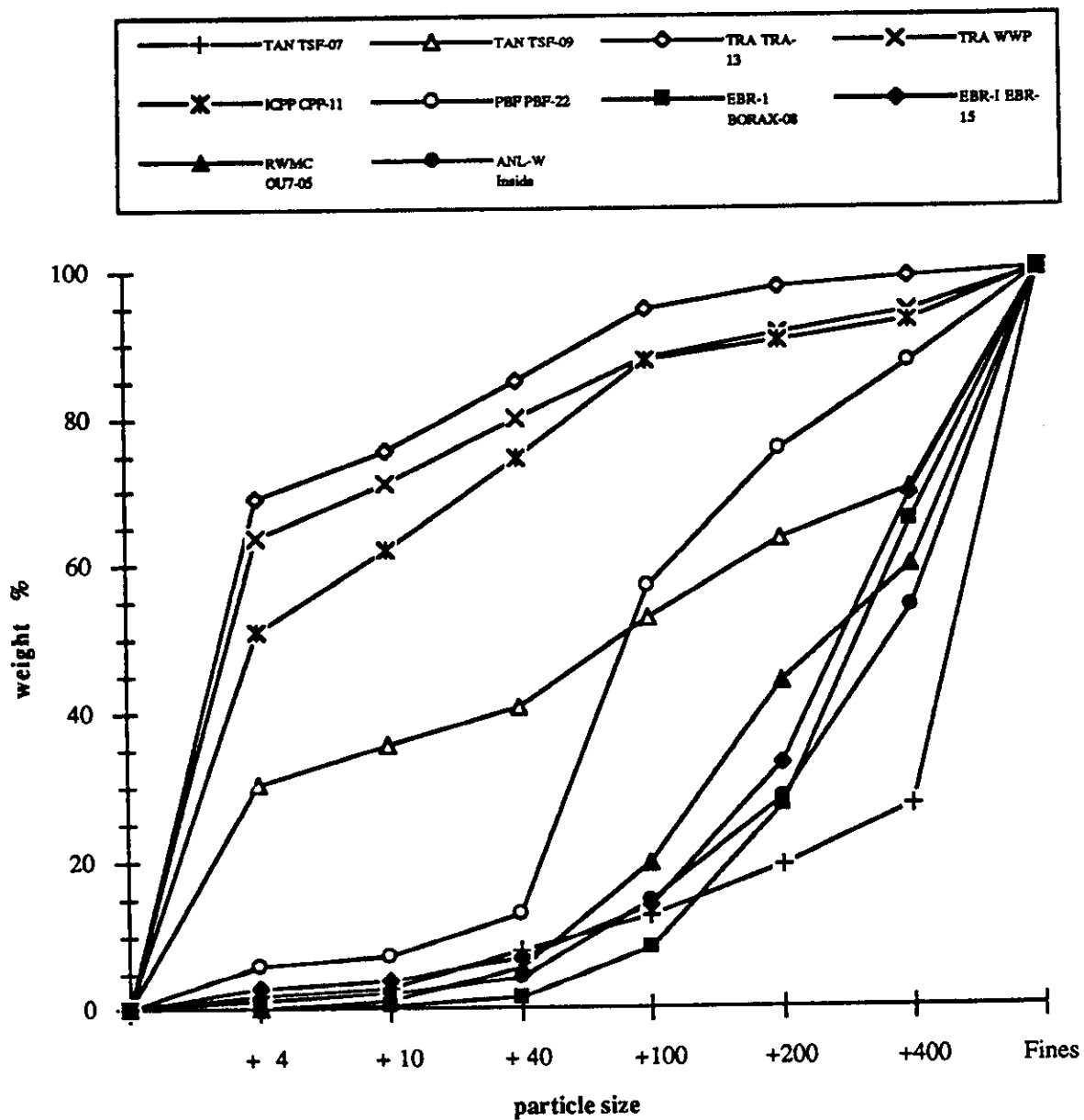
<b>WAG ID</b>	<b>OU ID</b>	<b>Sample Location ID</b>	<b>Postulated Mode of Deposition</b>
<b>WAG 1 (TAN)</b>	1-05	TSF-09	Surface liquid spills and runoff.
	1-06	TSF-07	Process water outfall.
	1-08	TSF-03	Windblown particulate.
<b>WAG 2 (TRA)</b>	2-04	TRA-WWP	Surface liquid spills around WWP.
	2-09	TRA 13	Sanitary water outfall.
<b>WAG 3 (ICPP)</b>	3-08	CPP-13	Air release of solid particulate.
	3-09	CPP-03	Contaminated lay-down area.
		CPP-11	Surface liquid spill w/particulate.
		CPP-22	Air release of solid particulate.
<b>WAG 5 (PBF/ARA)</b>	5-05	Outside	Airborne particulate from plume.
		ARA-06	Solid particulate spread by waste handling after SL-1 incident.
		Soil Box	Solid particulate spread by waste handling after SL-1 incident.
		East of SL-1	Windblown particulate.
		West of SL-1	Windblown particulate.
	5-09	PBF-22	Process water outfall.
		Outside	Windblown particulate.
<b>WAG 6 (EBR-1)</b>	6-02	BORAX-08	Process water outfall.
	6-04	EBR-15	NaK and aqueous surface spills.
<b>WAG 7 (RWMC)</b>	7-05	OU 7-05	Surface runoff particulate.
		Outside	Windblown particulate.
<b>WAG 9 (ANL-W)</b>	9-0	Inside	Process water outfall.

water movement. These categories are not absolute, but ideally the data would reflect the deposition mechanism. Aqueous deposition of dissolved contaminants may result in distribution on an atomic scale, driven primarily by particle surface area or cation exchange capacity. Particulate distributed from a stack plume should be very fine dust, or condensed aerosols which have passed around or through HEPA filters. Windblown material could be somewhat greater size (not filtered) but must still be small enough to be entrained by air movement. The third category may include soils, paint chips, or any other solids which have been moved by flooding, or materials handling without adequate confinement.

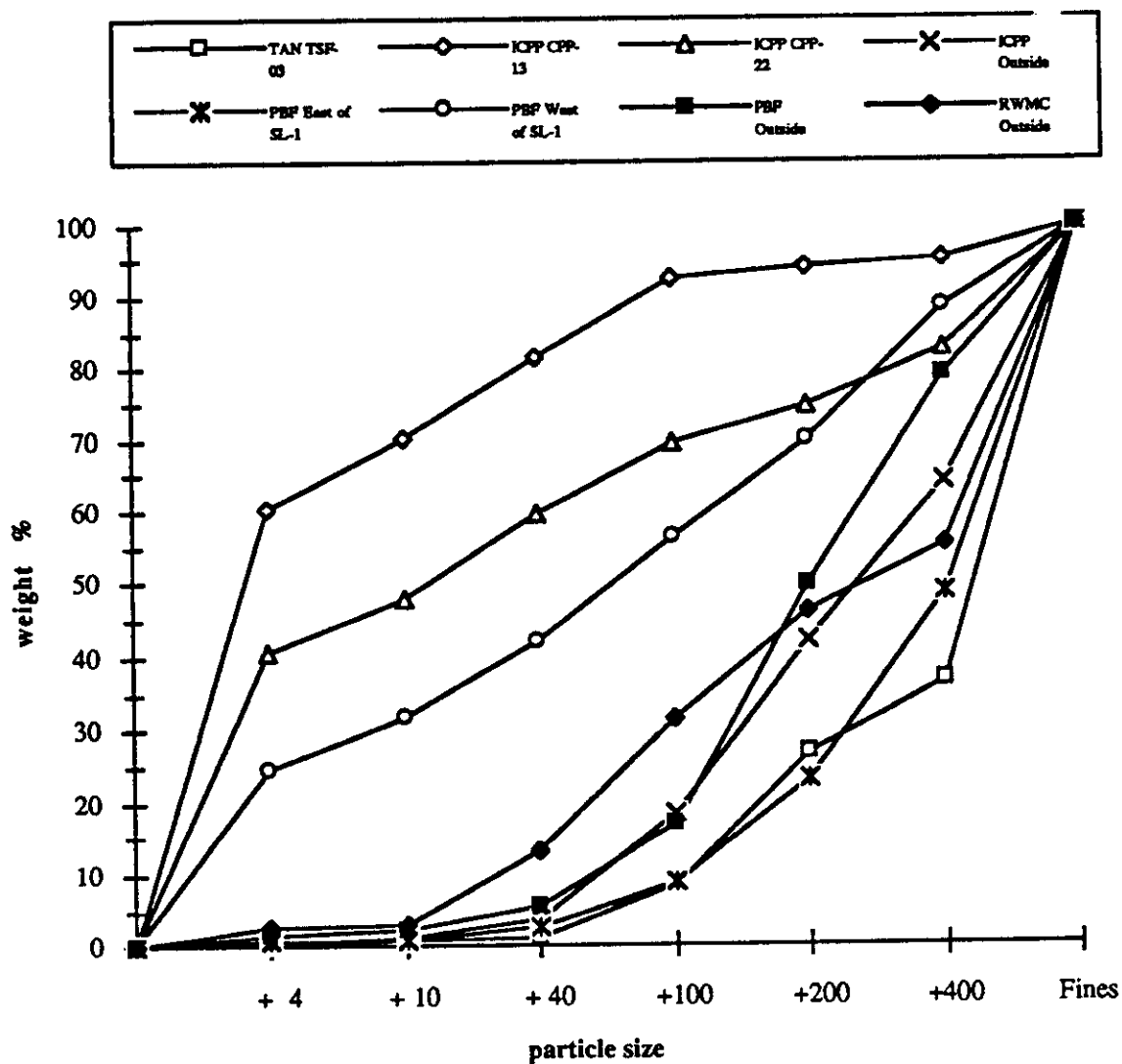
Plots of cumulative weight percent and particle size for the as-received samples are grouped by the three postulated depositional modes shown in Table 4-3 (Figures 4-5 through 4-7). No consistent relationship between depositional mode and particle size distribution is exhibited throughout the data. The similarities that are observed within each depositional mode grouping may be attributed to the four general soil types discussed above. The data may suggest that mode of deposition may not be a practical criterion for designing future sampling and analysis efforts. However, as previously stated, the data are from single samples representing a given type location, and without any knowledge of variation in each sample population it is impossible to move beyond speculation. More thorough assessment of the effects of contaminant deposition mode on particle size distribution at each RCS site may provide for firm conclusions on the possible relationship.

## **4.2 Particle Attrition**

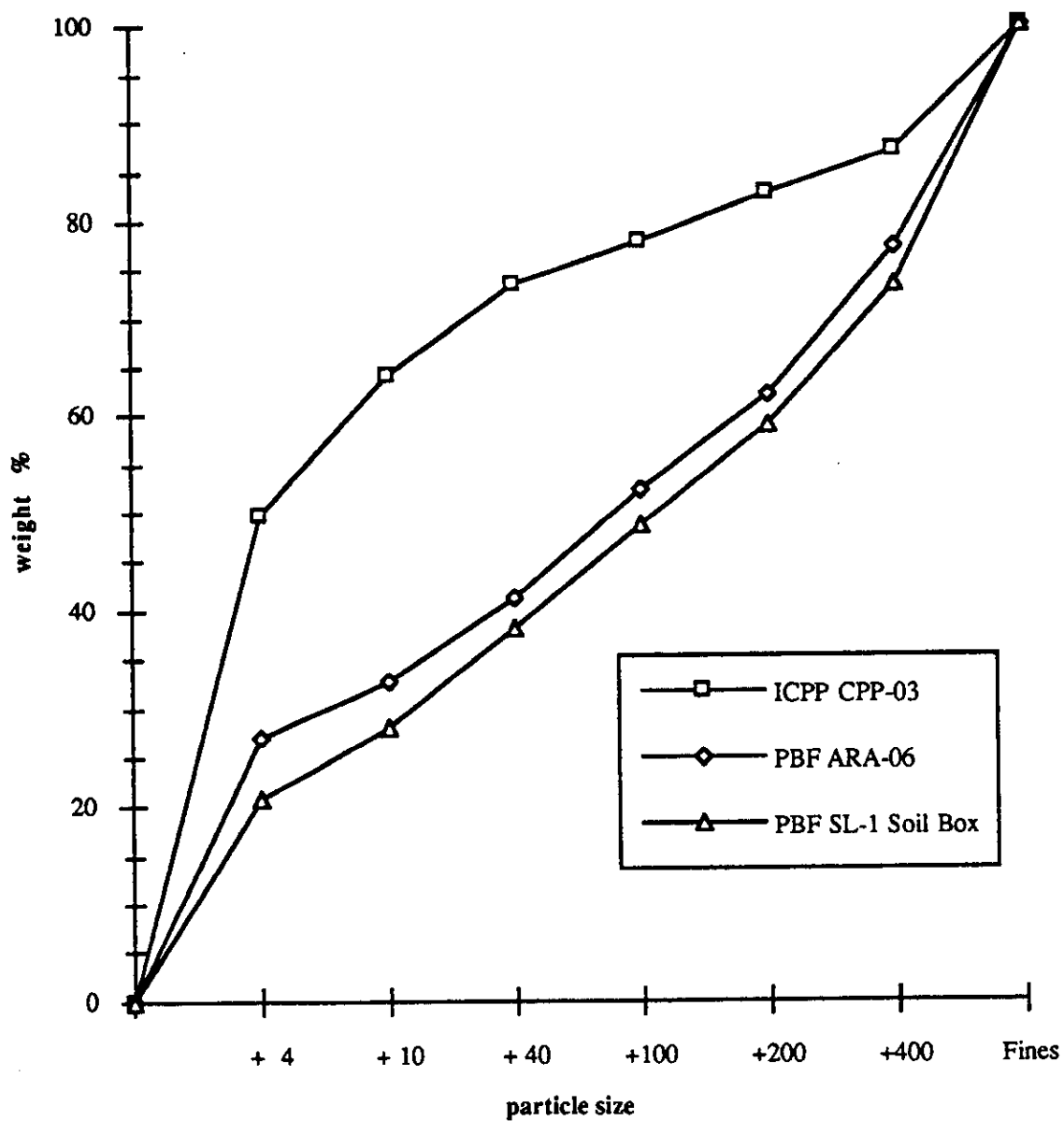
The "attrition" treatment used in the study was a very low energy procedure for "vigorous washing" adopted from EPA's laboratory in Montgomery, Alabama. The results (see Appendix A) are not conclusive, but may indicate whether significant gains can be made by mildly abrading the larger particles to more thoroughly remove contaminated fines (such as in a wet trommel); however, the results should not be interpreted to indicate the degree of decontamination that might be gained from a full-scale treatment.



**Figure 4-5.** Particle size distribution as cumulative weight percent for sample locations associated with aqueous deposition of dissolved species.



**Figure 4-6.** Particle size distribution as cumulative weight percent for sample locations associated with airborne distribution of fine particulate.



**Figure 4-7.** Particle size distribution as cumulative weight percent for sample locations associated with physical distribution by artificial means or gross water movement.

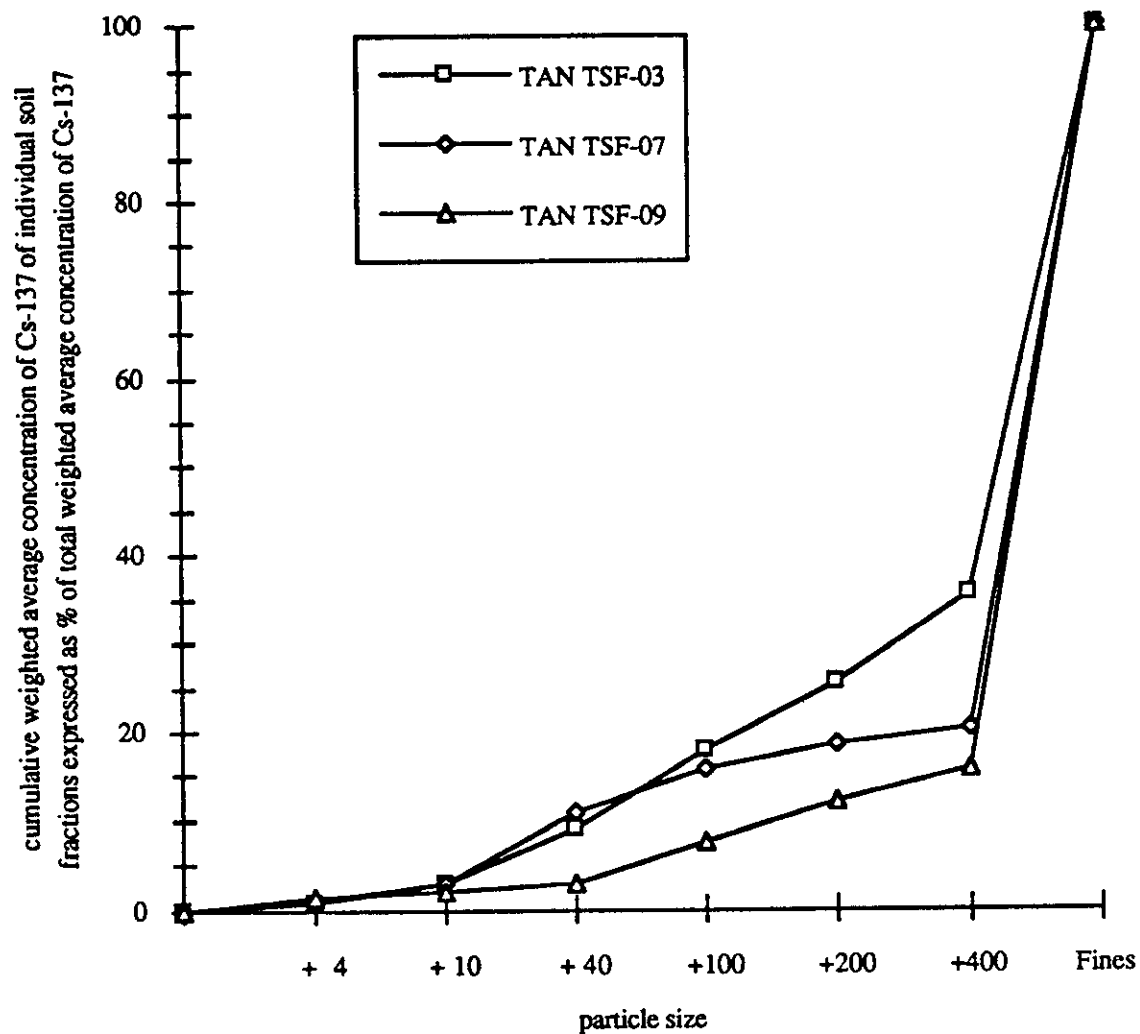
### 4.3 Radiological Measurements

Gamma spectrometry, gross alpha, and gross beta measurements were made on the field samples. The detailed results of the radiological measurements are presented in tabular form in Appendix A.

The most probable risk driver for radionuclide contamination in soils is  $^{137}\text{Cs}$ . The cumulative weighted average  $^{137}\text{Cs}$  concentration (expressed as % of total weighted average concentration) of the individual soil fractions of  $^{137}\text{Cs}$  was plotted for the as-received samples and grouped by the four general soil types given in Table 4-2 (Figures 4-8 through 4-11). The weighted average  $^{137}\text{Cs}$  data for as-received samples show general similarities within each of the four soil type groups (Figures 4-8 through 4-11). Again, the data may suggest that soil type may be a key factor to be considered in the design of future sampling and analysis efforts. Again, it is imperative to note that the data are single samples representing a given type location, and provide no knowledge of variation in each sample population. The  $^{137}\text{Cs}$  data also suggest that additional, more detailed information may need to be collected on soil types at each RCS site being considered.

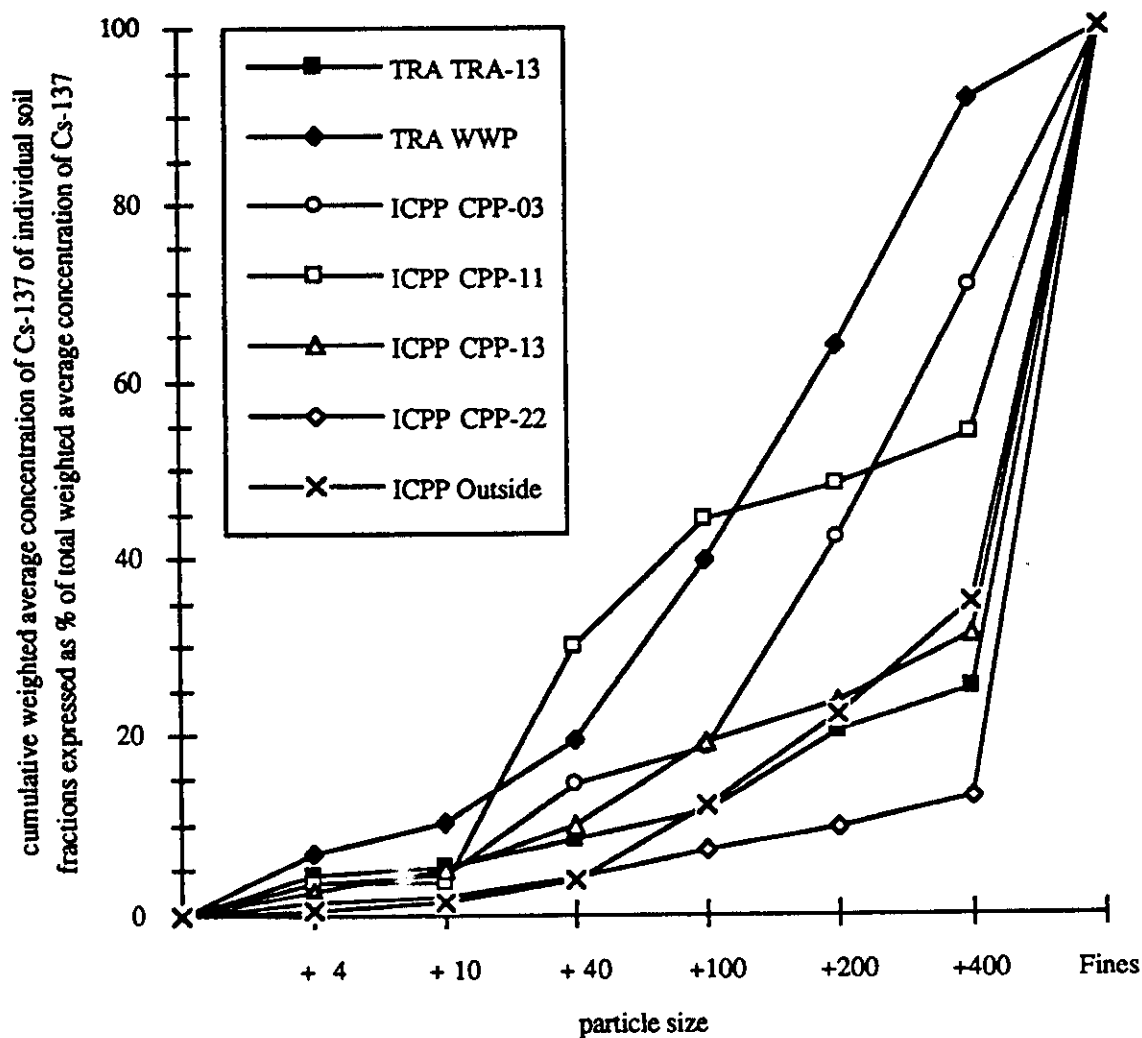
To observe possible similarities for  $^{137}\text{Cs}$  distribution within a given depositional mode, the cumulative weighted average  $^{137}\text{Cs}$  concentration (expressed as % of total weighted average concentration) of the individual soil fractions of  $^{137}\text{Cs}$  was plotted for the as-received samples and grouped by the three postulated depositional modes shown in Table 4-3 (Figures 4-12 through 4-14). The weighted average  $^{137}\text{Cs}$  data for as-received samples show some general similarities within each of the three postulated depositional modes (Figures 4-12 through 4-14); however as previously discussed, no consistent relationship between depositional mode and particle size distribution is exhibited throughout the data. The net result of the data analysis indicates that more thorough assessment of the effects of contaminant deposition mode at each RCS site would be necessary to proceed beyond speculation.

The analysts conducting the laboratory work reported several instances where samples or particle size fractions were largely of organic origin. Each particle size fraction was inspected for organic detritus. The larger size fractions, +4, and +10 mesh, had been ground so in many cases it was difficult to tell if they were primarily carbon or mineral based. Similarly, many of the fine fractions, -+400 mesh and fines, were difficult to judge other than by color, brown versus gray or white. Still, over 40 samples were identified that were obviously mainly organic, ranging from grass to peat moss in appearance. While many of these samples were significantly contaminated, there was no obvious correlation between the incidence of organic material and radionuclide content. Organic matter may account, however, for the anomalous distribution

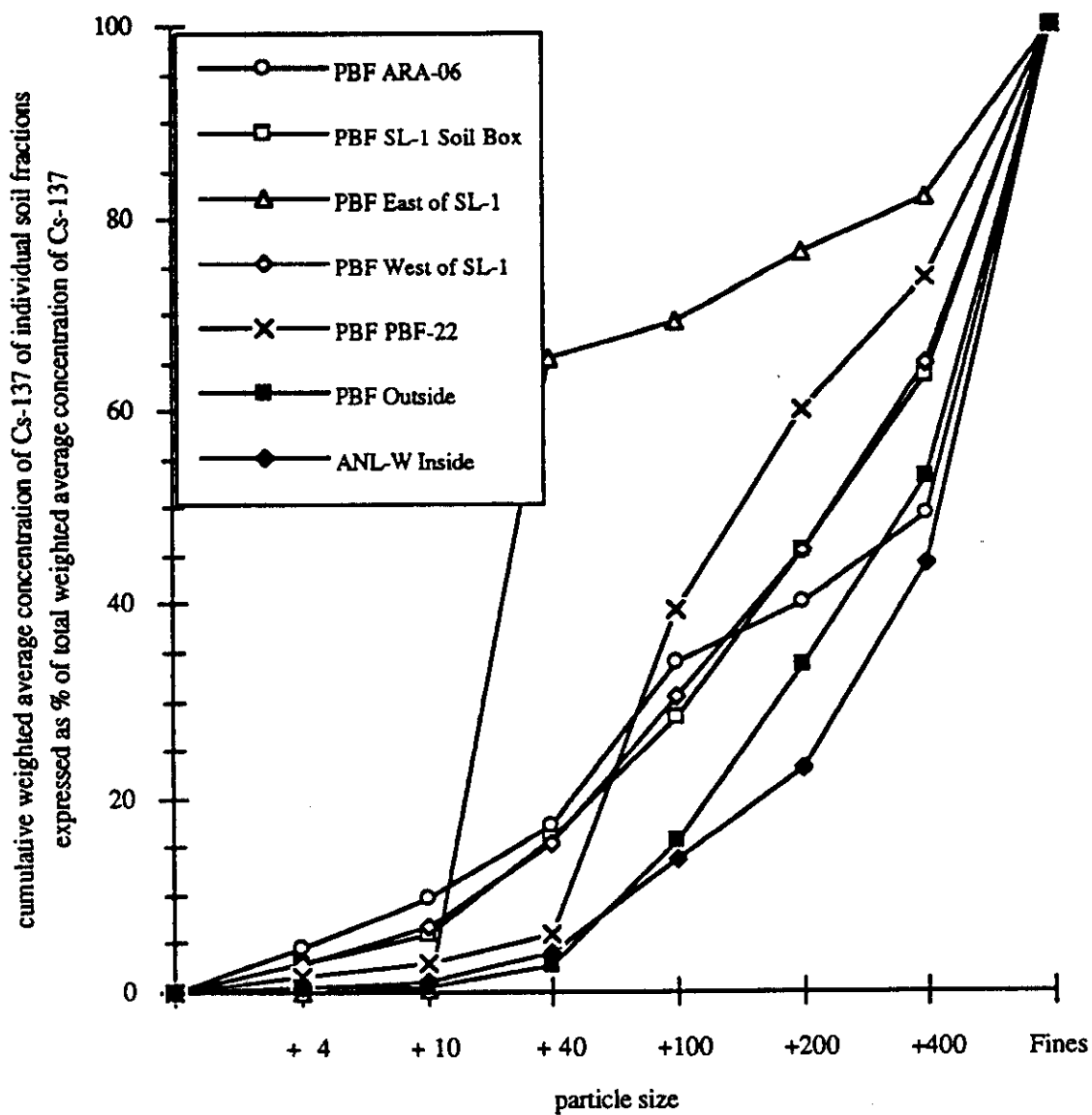


**Figure 4-8.** Cumulative weighted average  $^{137}\text{Cs}$  concentration of individual soil fractions for the WAG-1 (TAN) as-received samples.

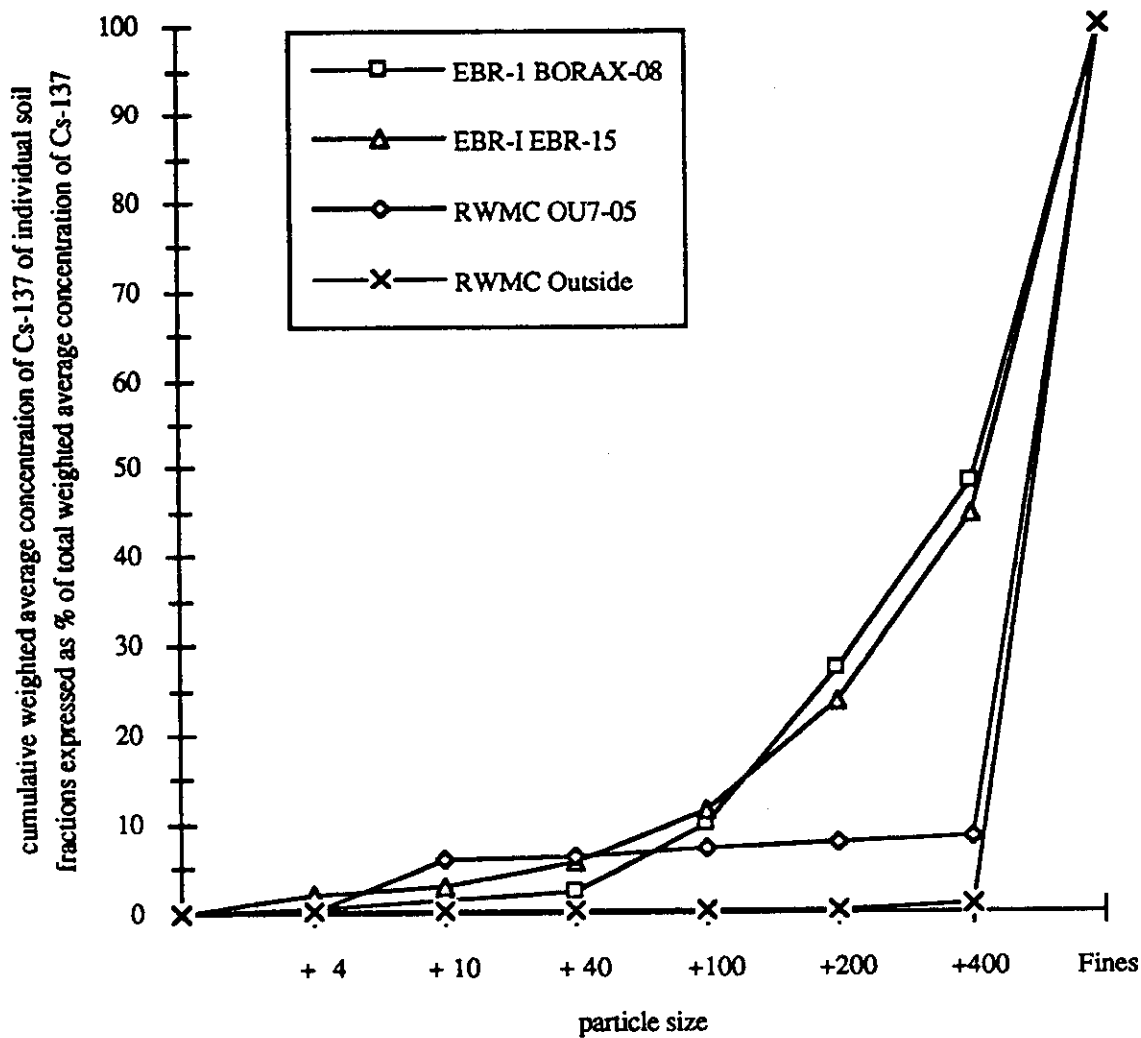




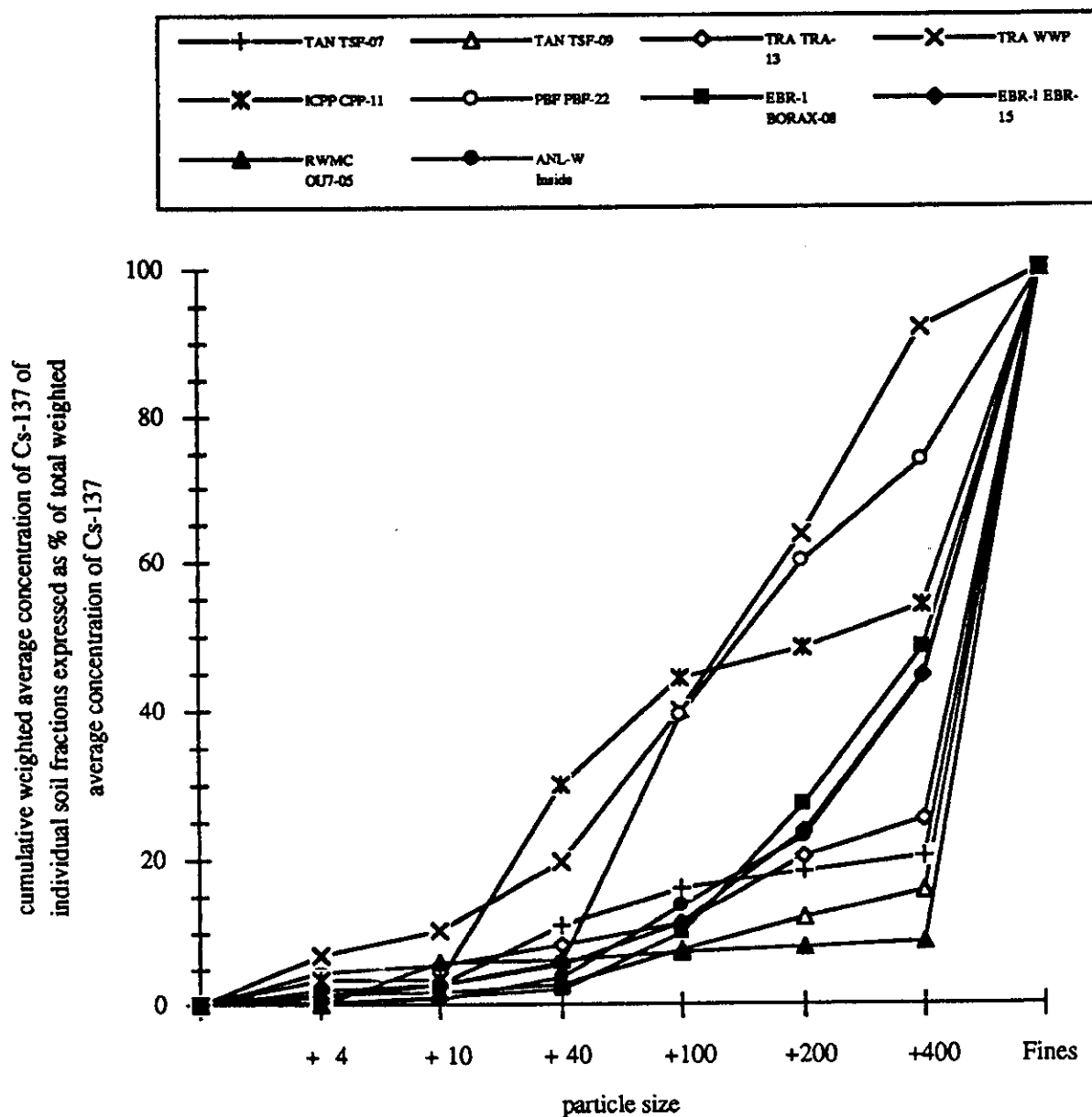
**Figure 4-9.** Cumulative weighted average  $^{137}\text{Cs}$  concentration of individual soil fractions for the WAG-2 (TRA) and WAG-3 (ICPP) as-received samples.



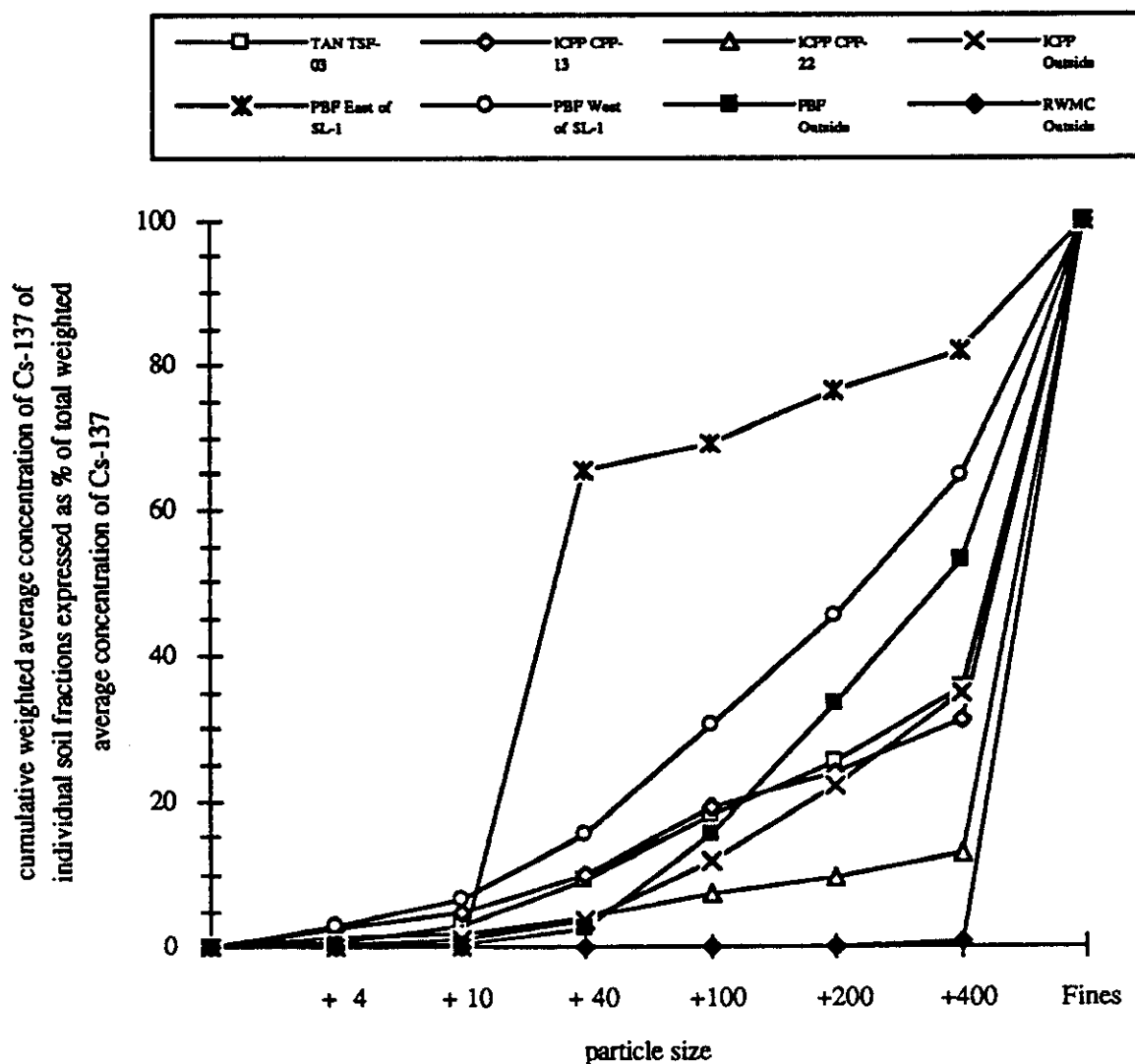
**Figure 4-10.** Cumulative weighted average  $^{137}\text{Cs}$  concentration of individual soil fractions for the WAG-5 (PBF) and WAG-9 (ANL-W) as-received samples.



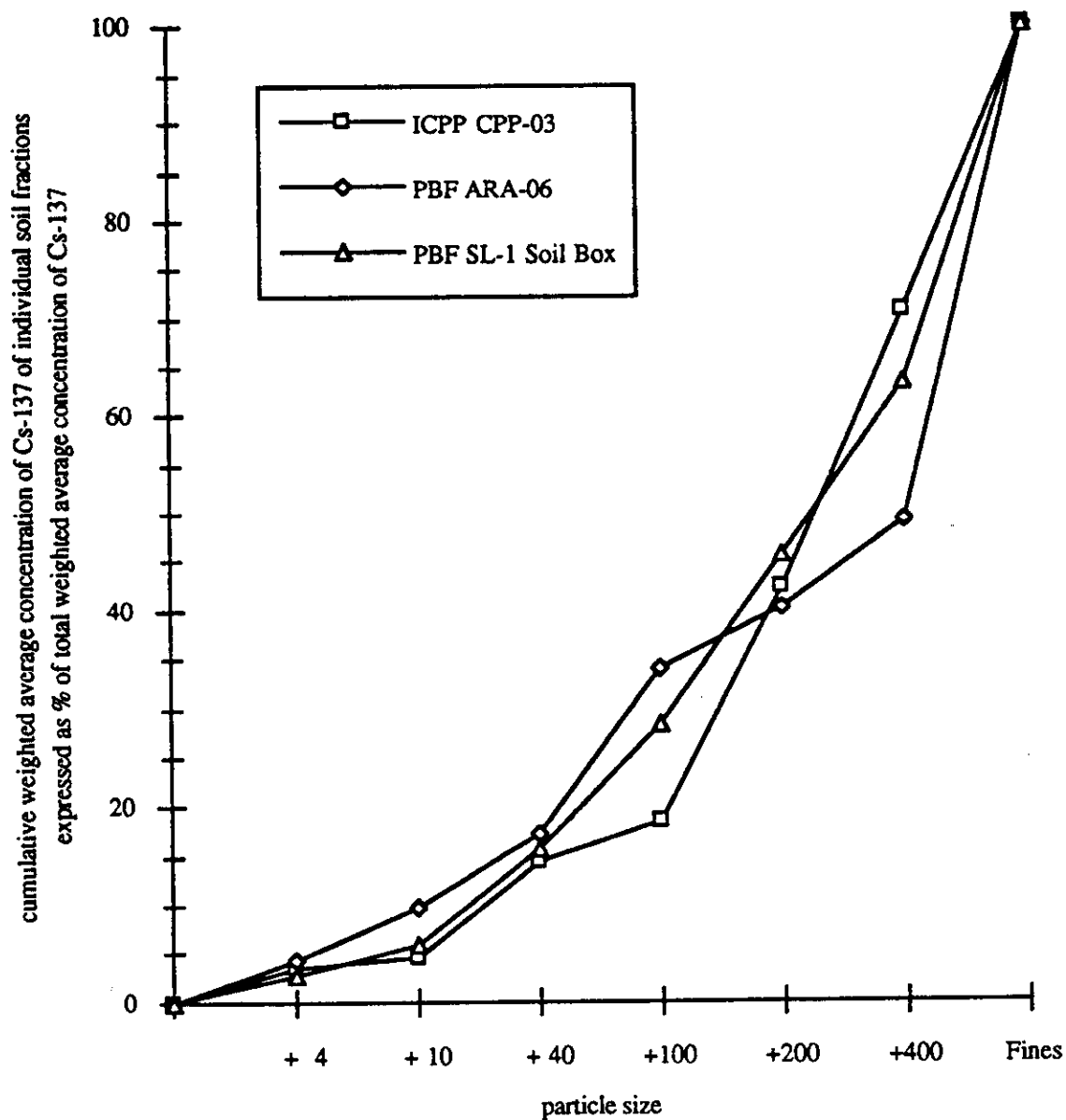
**Figure 4-11.** Cumulative weighted average  $^{137}\text{Cs}$  concentration of individual soil fractions for the WAG-6 (EBR-1) and WAG-7 (RWMC) as-received samples.



**Figure 4-12.** Cumulative weighted average  $^{137}\text{Cs}$  concentration of individual soil fractions for sample locations associated with aqueous deposition of dissolved species.



**Figure 4-13.** Cumulative weighted average  $^{137}\text{Cs}$  concentration of individual soil fractions for sample locations associated with airborne distribution of fine particulate.



**Figure 4-14.** Cumulative weighted average  $^{137}\text{Cs}$  concentration of individual soil fractions for sample locations associated with physical distribution by artificial means or gross water movement.

observed for some samples which did not show a monotonic increase in activity with decreasing particle size.

## **4.4 Data Limitations and Measurement Uncertainties**

### **4.4.1 Data Limitations**

The data are derived from single samples from each location. The natural heterogeneity of soil precludes the assumption that any of the samples represent the locations. Rather, the data are simply an indication of the types of contaminant distributions that can be found at the INEL. Compounding this issue is the fact that no duplicate analyses were done for the samples making it impossible to define the precision for the data. Results from the Warm Waste Pond treatability studies indicated a range of about  $\pm 20\%$  on triplicates taken from well-mixed samples. Variability of the results reported here was expected to be at least this great because the sample containers were not homogenized prior to removing material for sieving. The variability may be estimated by comparing the average activity between natural and attrited samples from the same site. Though the attrition may alter the distribution by particle size, the average contamination for the sample should remain constant. Averaging was maximized by splitting all of the material from the five-gallon sample received at the laboratory (random chute splitter) to create the analytical samples. This comparison indicates a typical precision of about a factor of two. Still, some samples are much closer (i.e. PBF-22,  $\pm 5\%$ ), while one very low activity sample from RWMC is much worse (RWMC OU7-05,  $\pm 1000\%$ ). This latter result was probably more a function of counting time than sample heterogeneity.

Also, early in this study, the decision was made that samples were to be divided by size alone. The samples are extremely variable in organic content, and some of the sieve fractions are essentially organic detritus with little or no mineral constituent. It may be advantageous to separate the organic fraction gravimetrically prior to treatment in a full-scale cleanup. The implication is that the sieve data may be biased by organic material reporting to a particulate size fraction, when on scale-up, it could be segregated, potentially carrying with it a significant amount of contamination. This bias probably most effects the larger size fractions, e.g. the results shown in the tables are probably worst-case, and the coarse material is probably cleaner than is indicated.

The "attrition" treatment used in the study was a very low energy procedure for "vigorous washing" adopted from the Montgomery, AL EPA laboratory. The results indicate if significant gains can be made by mildly abrading the larger particles to more thoroughly remove contaminated fines (such as in a wet trommel), but they should not be interpreted to indicate the

degree of decontamination that might be gained from a full-scale treatment. The use of aggressive attrition-scrubbing, separation of particle size fractions prior to attrition, surfactants, and froth-flotation, may produce a greater effect.

#### **4.4.2 Measurement Uncertainties**

The detection limit for the gamma spectrometry measurements was 0.5 pCi/g. Precision for the gamma spectrometry measurements is a function of the individual measurements. The required sensitivity for EPA method 9310 is 3 pCi/L for gross alpha and 4 pCi/L for gross beta (EPA 1986). Mass measurements were made to a precision of 0.01 g.



## 5.0 CONCLUSIONS AND RECOMMENDATIONS

Natural heterogeneity of the contaminated soils at the INEL preclude generalizations on contaminant distribution without significantly more analysis, and may not be possible even after a greater expenditure. The organic content of some samples may be separable by density to provide some degree of decontamination. Some volume reduction is potentially achievable at a 5 pCi/g allowable level of residual contamination. Volumes of contaminated soil at each sampled site are required to estimate the overall volume reduction potentially achievable.

Additional research could better define the decontamination achievable by more aggressive attrition scrubbing and density separation of organic material. The former could be simply tested by subjecting some of the samples already in inventory to varying exposures in an attrition mill or an inexpensive household blender. Particle size analysis versus radionuclide distribution similar to the data reported here could be used to more fully evaluate the potential for concentrating contamination in the fines. Separation of the organic material could be tested on select samples by sparging a water bath containing the contaminated soils. Most organic material should float to the top to be skimmed similar to the effect of a floatation cell.

Any further analysis should include homogenization and triplicate analyses on some samples to determine the analytical precision and confidence in the data.

### 5.1 Volume Reduction

The potential for volume reduction depends on the level of allowable residual contamination. Summarized in Table 5-1 are the estimated potential volume reductions achievable based on a range of allowable residual contamination levels ranging from one to one hundred picocuries per gram of  $^{137}\text{Cs}$ , the primary risk-driver. The values were calculated by choosing the smallest particle size for a sample above which the average contamination level meets the residual criteria. This may include a size fraction which, when taken alone, does not meet the criteria, but the composite larger-than fraction is acceptable. This rationale most closely approaches the actual commercial-scale process currently employed at hazardous waste sites.

Of the 21 samples, four have a significant (>50%) potential for volume reduction at an allowable level of 5 pCi/g, six samples at 10 pCi/g, and 10 at 25 pCi/g (Table 5-1). Increasing the level beyond 25 pCi/g has diminishing benefit, and decreasing below 5 pCi/g eliminates potential for volume reduction (Table 5-1). Insufficient data are available to estimate the impact on the total soil inventory by treating these particular sites.

**Table 5-1.** Volume reduction for selected residual <sup>137</sup>Cs activity levels.

	Mode of Deposition			Residual <sup>137</sup> Cs Activity Levels (pCi/g)					
				1	5	10	25	50	100
Sample Location	Aqueous	Airborne	Physical/ Aqueous	Weight % of Soil Meeting Residual Criteria					
TAN TSF-03		■		0	34	100	100	100	100
TAN TSF-07	■			0	0	0	0	0	0
TAN TSF-09	■			0	0	0	0	0	0
TRA-13	■			0	0	0	83	92	98
TRA WWP	■			41	83	100	100	100	100
ICPP CPP-03			■	0	0	0	51	63	63
ICPP CPP-11	■			0	0	0	0	0	0
ICPP CPP-13		■		0	0	0	62	81	92
ICPP CPP-22		■		0	58	81	81	81	100
ICPP Outside		■		0	39	100	100	100	100
PBF ARA-06			■	0	0	0	0	0	32
PBF East of SL-1		■		0	0	0	0	0	0
PBF West of SL-1		■		0	0	0	0	32	76
PBF SL-1 Soil Box			■	0	0	0	0	0	0
PBF-22	■			0	0	4	68	100	100
PBF Outside		■		0	0	0	0	0	0
EBR-I BORAX-08	■			0	0	0	0	0	0
EBR-I EBR-15	■			0	0	0	0	0	0
RWMC OU7-05	■			0	100	100	100	100	100
RWMC Outside		■		2	59	100	100	100	100
ANL-W Inside	■			0	0	4	5	46	100

## **5.2 Recommended Tasks**

As a result of the initial investigation on the physical removal of radionuclides in soil, the following tasks are recommended for the next phase of work:

- Decrease the error introduced by sample preparation methods and quantify sampling error (variability). Soil samples should be thoroughly homogenized prior to analyses and the degree of sample homogeneity should be measured. Sample preparation procedures such as grinding should minimize error of method by employing automated equipment instead of manual methods.
- Incorporate statistical measurements into future sampling and analysis efforts. The spatial variability of particle size distribution and radionuclide distribution should be determined for each sample population.
- Collect data to determine the feasibility of grouping soils by general soil type and determine the significance of depositional mode.
- Determine the organic content of sample populations. Evaluate the role of organic matter in the distribution of radionuclides. Collect data on the feasibility of the physical removal of organic matter from each sample population.
- Select a more aggressive attrition method. Determine the effects of a more aggressive attrition method.
- Determine the volumes of contaminated soil at each sampled site. Determine acceptable residual contaminant level(s). Estimate the overall volume reduction potentially achievable.

## 6.0 REFERENCES

- Barry, G. A. and M. H. Doornbos, 1993, *Sampling and Analysis Plan for the WAG 3/WAG 10 Radionuclide -Contaminated Soils Treatability Study*, MSE, Inc., August 1993.
- EG&G Idaho, Inc., 1993a, *Track 2 Field Sampling Plan for OU 1-04 and 1-05: Test Area North*, EGG-ER-10679, April.
- EG&G Idaho, Inc., 1993b, *Evaluation of Historical and Analytical Data on the TAN TSF-07 Disposal Pond*, EGG-ERD-10422, February.
- EG&G Idaho, Inc., 1993c, *Preliminary Scoping Track 2 Summary Report for Operable Unit 2-09: TRA Sewage Treatment Area and Cold Waste Pond*, EGG-ER-10595, July.
- EG&G Idaho, Inc., 1993d, *Track 1 Sites: Guidance for Assessing Low Probability Hazard Sites at the INEL*, June.
- EG&G Idaho, Inc., 1993e, *Scoping Track 2 Summary Report for Operable Unit OU 7-05: Surface Water Pathways and Surficial Sediments*, EGG-ERD-10449, January.
- EG&G Idaho, Inc., 1989, *Sampling and Analysis Plan for the SPERT-IV Leach Pond and Lake (COCA Units PBF-22 and -26)*, EGG-ER-8675, September.
- EPA, 1986, *Test Methods for Evaluating Solid Waste (SW-846): Physical/Chemical Methods, Third Edition*, U. S. Environmental Protection Agency, 1986.
- Idaho Department of Health and Welfare; U.S. Environmental Protection Agency; and U.S. Department of Energy Field Office, Idaho, 1991, *Action Plan for Implementation of the Federal Facility Agreement and Consent Order for the Idaho National Engineering Laboratory*, December, pp. 8 to 15.

**APPENDIX A**  
**Radionuclide and Particle Size Data**

Sample Log Number: 091016

ANL-W Inside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	36.35	24.58	11.77	1.3	5.9	8.7	17.9	17.9
+ 10	21.67	14.36	7.31	0.8	56.3	2076.6	25.5	20.8
+ 40	39.65	20.60	19.05	2.1	3.3	145.5	63.5	42.2
+100	114.74	20.48	94.26	10.5	5.0	45.5	42.2	42.2
+200	200.81	79.92	120.89	13.4	4.2	49.1	32.2	37.4
+400	312.23	79.83	232.40	25.8	4.9	35.0	37.6	37.5
Fines	707.56	293.83	413.73	46.0	4.8	44.9	55.4	45.7
Total	1433.01	533.60	899.41	100.0	5.2	61.1	45.7	

Sample Log Number: 091016 after attrition

ANL-W Inside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	175.18	129.32	45.86	7.0	6.9	5.6	1.3	1.3
+ 10	84.49	81.89	2.60	0.4	8.0	14.0	7.3	1.6
+ 40	88.28	82.08	6.20	0.9	15.0	40.5	96.5	12.4
+100	114.30	81.61	32.69	5.0	4.5	33.6	53.2	27.7
+200	133.41	82.04	51.37	7.8	4.2	32.4	46.5	34.6
+400	333.44	216.59	116.85	17.8	5.9	68.0	38.1	36.2
Fines	699.91	298.03	401.88	61.1	4.7	100.0	89.7	68.9
Total	1629.01	971.56	657.45	100.0	5.1	78.3	68.9	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091021

EBR-1 BORAX-08

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	93.33	90.21	3.12	0.3	4.2	27.7	605.4	605.4
+ 10	19.94	15.23	4.71	0.4	16.8	243.2	694.6	659.1
+ 40	25.08	15.04	10.04	0.8	13.3	216.7	408.1	518.1
+100	102.58	20.44	82.14	6.9	18.8	332.4	367.6	394.5
+200	304.72	79.89	224.83	18.8	5.0	299.5	313.5	338.4
+400	542.23	79.89	462.34	38.7	5.0	161.7	184.1	247.8
Fines	488.16	79.99	408.17	34.1	13.0	477.5	508.1	336.7
Total	1576.04	380.69	1195.35	100.0	8.8	307.6	336.7	

Sample Log Number: 091021 after attrition

EBR-1 BORAX-08

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	92.42	90.58	1.84	0.2	5.8	119.4	567.6	567.6
+ 10	94.23	91.37	2.86	0.3	13.9	331.5	783.8	699.1
+ 40	149.77	126.33	23.44	2.2	25.9	376.6	373.0	427.4
+100	186.17	126.46	59.71	5.7	22.5	345.5	451.4	443.7
+200	376.57	199.48	177.09	17.0	12.4	350.0	435.1	438.0
+400	746.72	293.76	452.96	43.4	11.4	254.1	383.8	403.8
Fines	324.60	0.00	324.60	31.1	8.5	282.4	810.8	530.5
Total	1970.48	927.98	1042.50	100.0	11.6	287.2	530.5	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091020

EBR-I EBR-15

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	45.16	20.77	24.39	2.7	5.5	139.6	187.0	187.0
+ 10	29.39	20.56	8.83	1.0	5.9	110.4	221.6	196.2
+ 40	52.16	24.26	27.90	3.1	5.8	205.0	211.1	203.0
+100	83.07	20.64	62.43	7.0	8.5	201.8	198.9	200.9
+200	202.99	31.19	171.80	19.2	9.5	150.0	157.6	175.7
+400	404.66	79.99	324.67	36.3	11.3	133.3	142.7	158.4
Fines	353.04	79.83	273.21	30.6	18.4	392.3	443.2	245.5
Total	1170.47	277.24	893.23	100.0	12.6	222.7	245.5	

Sample Log Number: 091020 after attrition

EBR-I EBR-15

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	106.50	81.99	24.51	2.7	14.5	23.3	33.5	33.5
+ 10	91.59	82.21	9.38	1.0	5.5	139.2	237.8	90.1
+ 40	36.28	14.37	21.91	2.4	4.2	5.7	808.1	372.0
+100	287.72	199.66	88.06	9.7	5.5	7.6	248.6	296.5
+200	396.54	199.68	196.86	21.6	4.9	6.6	194.9	237.8
+400	651.57	303.32	348.25	38.2	4.3	5.8	193.5	215.4
Fines	421.54	199.56	221.98	24.4	4.9	6.4	340.5	245.9
Total	1991.74	1080.79	910.95	100.0	5.0	8.1	245.9	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.



Sample Log Number: 082712

ICPP CPP-03

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1330.22	134.63	1195.59	49.7	15.4	200.9	15.1	15.1
+ 10	427.58	79.90	347.68	14.4	12.0	62.2	14.3	14.9
+ 40	267.89	41.48	226.41	9.4	8.7	189.2	225.9	41.9
+100	126.56	20.53	106.03	4.4	24.2	364.4	197.8	50.7
+200	158.56	41.66	116.90	4.9	82.9	1216.2	1043.2	109.0
+400	146.72	41.30	105.42	4.4	49.5	1081.1	1383.8	173.0
Fines	389.50	79.89	309.61	12.9	57.2	1707.2	486.5	213.3
Total	2847.03	439.39	2407.64	100.0	24.8	468.5	213.3	

Sample Log Number: 082712 after attrition

ICPP CPP-03

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	664.86	107.65	557.21	23.2	4.7	118.5	14.6	14.6
+ 10	428.29	79.86	348.43	14.5	13.2	169.8	24.8	18.6
+ 40	411.34	38.18	373.16	15.5	4.4	204.1	36.2	23.7
+100	494.07	79.78	414.29	17.2	6.9	224.3	3135.1	785.1
+200	187.64	38.19	149.45	6.2	10.9	495.5	149.7	733.5
+400	187.64	37.78	149.86	6.2	60.4	3243.2	242.4	696.6
Fines	580.86	170.92	409.94	17.1	55.4	1797.3	567.6	674.6
Total	2954.70	552.36	2402.34	100.0	18.8	662.3	674.6	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 08279

ICPP CPP-11

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1472.93	137.18	1335.75	50.9	8.8	23.2	127.8	127.8
+ 10	372.58	79.83	292.75	11.2	21.4	29.7	0.0	104.9
+ 40	621.85	292.78	329.07	12.5	40.5	1405.4	3810.8	727.8
+100	637.52	294.04	343.48	13.1	51.4	2144.1	1991.9	916.5
+200	89.07	20.72	68.35	2.6	98.6	3765.8	2729.7	968.8
+400	86.89	20.74	66.15	2.5	102.7	5450.5	4162.2	1055.6
Fines	377.74	189.57	188.17	7.2	255.4	11846.8	11594.6	1811.4
Total	3658.58	1034.86	2623.72	100.0	42.2	1557.2	1811.4	

Sample Log Number: 08279 after attrition

ICPP CPP-11

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1752.76	143.30	1609.46	57.9	30.6	284.7	116.8	116.8
+ 10	581.61	293.97	287.64	10.3	65.8	797.3	297.3	144.1
+ 40	440.86	79.89	360.97	13.0	72.1	2896.4	2527.0	525.1
+100	298.98	36.25	262.73	9.4	48.2	1504.5	1775.7	655.4
+200	77.55	24.45	53.10	1.9	59.5	2549.5	2254.1	688.4
+400	79.01	24.46	54.55	2.0	99.5	3427.9	1091.9	696.8
Fines	173.94	20.46	153.48	5.5	427.5	15630.6	14162.2	1439.6
Total	3404.71	622.78	2781.93	100.0	65.1	1743.3	1439.6	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 082616

ICPP CPP-13

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1170.80	102.12	1068.68	60.5	2.6	143.2	17.9	17.9
+ 10	193.59	20.42	173.17	9.8	11.8	250.0	95.7	28.7
+ 40	282.79	79.94	202.85	11.5	18.6	323.0	173.0	49.0
+100	209.56	20.63	188.93	10.7	11.5	783.8	348.6	83.6
+200	44.28	15.29	28.99	1.6	60.8	1180.2	1181.1	102.8
+400	17.37	0.00	17.37	1.0	79.3	2783.8	3054.1	133.3
Fines	256.84	169.47	87.37	4.9	180.2	7162.2	5675.7	407.3
Total	2175.23	407.87	1767.36	100.0	16.8	632.7	407.3	

Sample Log Number: 082616 after attrition

ICPP CPP-13

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1271.23	143.92	1127.31	63.1	13.0	118.0	28.9	28.9
+ 10	162.45	24.64	137.81	7.7	12.6	211.7	81.4	34.6
+ 40	194.49	24.52	169.97	9.5	13.9	310.4	149.5	48.2
+100	158.00	20.74	137.26	7.7	10.9	432.4	231.4	64.2
+200	45.78	15.03	30.75	1.7	25.0	644.1	283.8	68.4
+400	33.04	14.36	18.68	1.0	66.7	1693.7	1621.6	86.3
Fines	458.05	294.26	163.79	9.2	132.9	459.5	3918.9	437.9
Total	2323.04	537.47	1785.57	100.0	24.7	224.6	437.9	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 082711  
ICPP CPP-22  
Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1274.32	105.01	1169.31	40.7	13.7	22.8	2.4	2.4
+ 10	239.03	23.40	215.63	7.5	13.1	31.4	5.2	2.8
+ 40	409.56	79.36	330.20	11.5	11.6	38.2	12.1	4.6
+100	323.20	41.13	282.07	9.8	11.4	37.4	21.8	7.0
+200	168.66	21.38	147.28	5.1	11.8	39.4	29.5	8.6
+400	272.24	35.72	236.52	8.2	12.2	45.9	27.8	10.5
Fines	809.10	314.42	494.68	17.2	30.9	567.6	337.8	66.8
Total	3496.11	620.42	2875.69	100.0	15.9	123.1	66.8	

Sample Log Number: 082711 after attrition  
ICPP CPP-22  
Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1205.93	137.38	1068.55	37.9	4.1	21.6	3.7	3.7
+ 10	222.15	31.25	190.90	6.8	3.5	17.7	5.3	3.9
+ 40	358.86	31.75	327.11	11.6	8.2	18.5	7.1	4.6
+100	315.69	31.25	284.44	10.1	13.0	44.1	13.5	5.9
+200	160.61	20.72	139.89	5.0	22.8	120.3	25.8	7.3
+400	260.94	31.02	229.92	8.2	8.9	87.4	8.2	7.4
Fines	998.68	422.42	576.26	20.5	14.4	442.3	255.1	58.1
Total	3522.86	705.79	2817.07	100.0	8.9	119.6	58.1	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091018

ICPP Outside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	26.31	20.77	5.54	0.6	6.6	10.5	8.2	8.2
+ 10	20.18	15.19	4.99	0.5	4.4	17.4	14.2	11.0
+ 40	45.87	20.54	25.33	2.8	4.5	12.7	8.4	9.1
+100	153.61	20.83	132.78	14.5	4.4	7.9	5.5	6.3
+200	296.82	79.78	217.04	23.7	6.9	8.1	4.2	5.1
+400	280.91	79.84	201.07	21.9	15.4	8.2	5.6	5.3
Fines	624.32	293.75	330.57	36.0	10.7	59.5	17.4	9.6
Total	1448.02	530.70	917.32	100.0	9.7	26.8	9.6	

Sample Log Number: 091018 after attrition

ICPP Outside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	133.35	128.50	4.85	0.5	12.2	18.8	14.9	14.9
+ 10	134.13	128.88	5.25	0.6	9.8	11.6	14.1	14.5
+ 40	223.95	199.10	24.85	2.8	4.3	12.2	7.8	9.8
+100	131.55	20.75	110.80	12.4	4.4	8.0	3.7	5.2
+200	377.08	199.98	177.10	19.9	8.3	8.0	4.2	4.6
+400	391.37	199.48	191.89	21.5	10.0	11.1	5.8	5.1
Fines	806.27	430.33	375.94	42.2	11.2	8.1	6.5	5.7
Total	2197.70	1307.02	890.68	100.0	9.3	8.9	5.7	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091619

PBF ARA-06

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	406.74	199.50	207.24	27.0	4.5	93.7	53.2	53.2
+ 10	134.26	90.23	44.03	5.7	7.0	426.1	297.3	96.0
+ 40	193.25	128.05	65.20	8.5	13.2	374.3	291.9	136.4
+100	212.73	126.57	86.16	11.2	14.0	411.3	483.8	210.7
+200	201.21	126.78	74.43	9.7	19.0	191.9	209.5	210.5
+400	245.14	127.21	117.93	15.4	11.4	155.4	191.1	206.7
Fines	172.72	0.00	172.72	22.5	9.0	522.5	732.4	325.0
Total	1566.05	798.34	767.71	100.0	10.0	287.7	325.0	

Sample Log Number: 091619 after attrition

PBF ARA-06

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	481.00	199.37	281.63	24.2	8.6	91.0	65.1	65.1
+ 10	89.34	15.03	74.31	6.4	12.6	168.9	173.5	87.8
+ 40	112.49	24.57	87.92	7.6	5.4	171.6	418.9	153.4
+100	233.12	128.83	104.29	9.0	8.8	240.5	343.2	189.5
+200	212.30	128.03	84.27	7.2	3.8	332.9	305.4	204.9
+400	309.36	148.48	160.88	13.8	5.7	177.9	157.6	195.3
Fines	672.01	301.60	370.41	31.8	27.3	177.9	791.9	385.2
Total	2109.62	945.91	1163.71	100.0	13.9	172.7	385.2	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091620

PBF East of SL-1

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	95.02	89.02	6.00	0.7	37.2	689.2	22.7	22.7
+ 10	92.61	91.43	1.18	0.1	304.5	4549.5	159.7	45.2
+ 40	141.80	126.63	15.17	1.8	19.1	743.2	16973.0	11534.9
+100	177.05	127.42	49.63	6.0	15.0	448.6	308.1	3794.1
+200	317.46	199.40	118.06	14.2	3.5	191.0	241.9	1587.3
+400	412.84	199.71	213.13	25.7	50.5	1941.4	104.9	803.6
Fines	505.31	79.83	425.48	51.3	23.5	955.0	165.4	475.9
Total	1742.09	913.44	828.65	100.0	27.5	1068.8	475.9	

Sample Log Number: 091620 after attrition

PBF East of SL-1

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	21.78	20.79	0.99	0.2	150.5	2171.2	195.9	195.9
+ 10	21.22	20.70	0.52	0.1	24.3	576.6	359.5	252.3
+ 40	90.54	81.73	8.81	1.4	56.3	1477.5	60810.8	51950.0
+100	58.37	20.76	37.61	5.9	43.1	864.9	1637.8	12470.8
+200	102.94	20.69	82.25	12.9	20.2	486.5	141.9	4681.2
+400	176.56	20.89	155.67	24.4	27.3	959.5	99.7	2186.2
Fines	424.39	72.29	352.10	55.2	255.9	8738.7	260.3	1123.2
Total	895.80	257.85	637.95	100.0	154.0	5195.2	1123.2	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091023

PBF (SPERT 4) PBF-22

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	104.95	38.26	66.69	5.9	4.9	8.0	9.2	9.2
+ 10	28.21	15.18	13.03	1.2	22.4	729.7	41.9	14.6
+ 40	157.00	91.38	65.62	5.8	12.9	38.9	17.6	15.9
+100	789.86	293.71	496.15	44.2	8.6	140.5	26.0	23.7
+200	229.72	24.61	205.11	18.3	25.4	445.0	39.2	27.5
+400	263.91	128.89	135.02	12.0	17.4	77.0	39.2	29.1
Fines	435.82	294.22	141.60	12.6	21.7	173.4	71.6	34.4
Total	2009.47	886.25	1123.22	100.0	14.5	185.7	34.4	

Sample Log Number: 091023 after attrition

PBF (SPERT 4) PBF-22

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	160.87	130.33	30.54	2.8	5.0	8.0	10.6	10.6
+ 10	142.39	128.76	13.63	1.2	4.4	8.1	20.2	13.6
+ 40	188.74	128.87	59.87	5.5	14.8	16.6	19.6	17.0
+100	432.81	80.06	352.75	32.3	12.3	46.4	17.3	17.2
+200	392.89	199.68	193.21	17.7	6.0	13.6	25.8	19.8
+400	329.19	216.27	112.92	10.3	11.7	23.9	28.9	21.1
Fines	657.38	329.20	328.18	30.1	9.2	79.3	71.4	36.2
Total	2304.27	1213.17	1091.10	100.0	10.0	45.0	36.2	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.



Sample Log Number: 091025

PBF Outside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	103.22	90.02	13.20	1.6	10.0	251.4	230.3	230.3
+ 10	18.15	14.38	3.77	0.5	107.7	3247.7	120.3	205.8
+ 40	41.09	14.39	26.70	3.3	40.0	1184.7	556.8	420.4
+100	182.84	90.74	92.10	11.4	33.6	711.7	959.5	786.1
+200	377.65	110.71	266.94	32.9	18.0	549.5	464.9	573.2
+400	286.77	48.80	237.97	29.4	23.4	509.0	562.2	569.1
Fines	214.60	44.96	169.64	20.9	59.0	1513.5	1908.1	849.4
Total	1224.32	414.00	810.32	100.0	31.0	786.5	849.4	

Sample Log Number: 091025 after attrition

PBF Outside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	93.79	89.82	3.97	0.5	10.3	280.6	445.9	445.9
+ 10	93.46	89.54	3.92	0.5	21.5	635.1	36.8	242.6
+ 40	114.12	90.23	23.89	3.0	18.8	495.5	600.0	511.3
+100	200.07	126.01	74.06	9.4	34.6	1022.5	864.9	758.7
+200	433.08	199.32	233.76	29.6	21.7	684.7	775.7	770.4
+400	481.54	199.79	281.75	35.6	30.0	671.2	540.0	665.9
Fines	368.23	199.20	169.03	21.4	21.9	779.3	153.2	556.3
Total	1784.29	993.91	790.38	100.0	25.8	723.8	556.3	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091621

PBF SL-1 Soil Box

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	427.50	200.68	226.82	20.9	13.1	415.3	253.2	253.2
+ 10	208.67	130.72	77.95	7.2	21.5	1711.7	762.2	383.4
+ 40	239.48	130.27	109.21	10.0	14.2	3882.9	1845.9	769.2
+100	245.42	130.61	114.81	10.6	6.8	3738.7	2200.0	1079.9
+200	244.58	132.39	112.19	10.3	11.5	4103.6	3108.1	1434.9
+400	238.45	79.54	158.91	14.6	14.6	3013.5	2273.0	1601.4
Fines	358.45	70.76	287.69	26.5	54.1	3585.6	2559.5	1854.8
Total	1962.55	874.97	1087.58	100.0	24.0	2806.0	1854.8	

Sample Log Number: 091621 after attrition

PBF SL-1 Soil Box

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	541.81	194.75	347.06	31.2	37.6	1409.9	169.7	169.7
+ 10	146.92	81.50	65.42	5.9	116.7	4027.0	1029.7	306.1
+ 40	90.93	24.62	66.31	6.0	45.5	1657.7	664.9	355.8
+100	207.59	137.86	69.73	6.3	67.6	2671.2	1859.5	547.0
+200	86.39	24.47	61.92	5.6	211.7	7387.4	3405.4	836.9
+400	320.05	191.33	128.72	11.6	150.0	7117.1	2054.1	1048.9
Fines	445.75	72.57	373.18	33.5	105.4	4130.6	3702.7	1939.2
Total	1839.44	727.10	1112.34	100.0	90.0	3563.6	1939.2	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091622

PBF West of SL-1

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	476.11	217.82	258.29	24.5	4.5	9.1	27.6	27.6
+ 10	204.23	126.50	77.73	7.4	3.1	138.7	108.6	46.3
+ 40	133.29	24.53	108.76	10.3	6.8	183.8	190.3	81.5
+100	278.15	129.04	149.11	14.2	13.8	222.1	239.2	121.1
+200	271.83	128.07	143.76	13.7	8.1	208.6	248.4	145.9
+400	410.04	216.71	193.33	18.4	8.5	207.7	236.2	164.7
Fines	321.13	199.47	121.66	11.6	10.9	585.6	681.1	224.4
Total	2094.78	1042.14	1052.64	100.0	7.9	197.2	224.4	

Sample Log Number: 091622 after attrition

PBF West of SL-1

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	469.88	216.64	253.24	24.5	6.0	43.6	40.0	40.0
+ 10	163.45	82.05	81.40	7.9	3.5	73.4	78.6	49.4
+ 40	172.72	81.65	91.07	8.8	4.0	115.3	159.7	73.0
+100	329.11	217.24	111.87	10.8	7.9	235.6	201.9	99.8
+200	257.74	129.90	127.84	12.4	4.4	171.6	218.6	122.7
+400	462.94	217.65	245.29	23.8	10.3	141.9	123.0	122.7
Fines	321.13	199.47	121.66	11.8	18.3	320.3	245.7	137.2
Total	2176.97	1144.60	1032.37	100.0	8.1	144.9	137.2	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 090712

RWMC OU7-05

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	22.11	20.93	1.18	0.1	8.7	13.3	13.5	13.5
+ 10	29.65	20.97	8.68	1.0	7.4	59.5	53.0	48.2
+ 40	62.42	20.83	41.59	4.6	5.5	21.6	0.9	10.0
+100	146.32	20.86	125.46	13.9	9.2	7.6	0.6	3.3
+200	258.64	36.54	222.10	24.6	5.5	27.3	0.2	1.6
+400	164.88	24.70	140.18	15.5	5.6	21.2	0.3	1.3
Fines	578.27	213.36	364.91	40.4	6.6	396.4	20.4	9.0
Total	1262.29	358.19	904.10	100.0	6.5	172.6	9.0	

Sample Log Number: 090712 after attrition

RWMC OU7-05

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	86.19	81.86	4.33	0.4	8.7	16.8	0.0	0.0
+ 10	83.48	81.69	1.79	0.2	12.3	15.2	0.0	0.0
+ 40	102.13	81.82	20.31	2.0	7.8	7.3	6.1	4.7
+100	118.27	24.74	93.53	9.4	5.6	7.3	1.2	2.0
+200	161.66	20.41	141.25	14.2	6.4	10.7	0.0	0.9
+400	451.81	217.08	234.73	23.6	5.1	6.7	0.6	0.8
Fines	793.76	295.60	498.16	50.1	5.1	6.5	0.8	0.8
Total	1797.30	803.20	994.10	100.0	5.4	7.3	0.8	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 090711

RWMC Outside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	119.46	90.32	29.14	2.6	5.0	7.4	0.4	0.4
+ 10	95.74	90.58	5.16	0.5	5.3	8.4	0.0	0.3
+ 40	114.02	0.00	114.02	10.1	10.3	8.2	0.0	0.1
+100	227.96	20.51	207.45	18.3	4.5	8.1	0.0	0.0
+200	193.34	24.62	168.72	14.9	5.2	8.2	0.0	0.0
+400	127.02	24.39	102.63	9.0	4.7	8.1	0.6	0.1
Fines	587.18	79.94	507.24	44.7	19.1	89.2	21.3	9.6
Total	1464.72	330.36	1134.36	100.0	11.8	44.4	9.6	

Sample Log Number: 090711 after attrition

RWMC Outside

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	32.40	15.01	17.39	1.8	116.7	5720.7	1.2	1.2
+ 10	19.62	15.06	4.56	0.5	6.9	52.3	14.6	4.0
+ 40	72.09	24.67	47.42	4.9	6.9	400.9	1.6	2.3
+100	251.81	48.74	203.07	21.1	4.7	7.9	0.8	1.2
+200	164.20	24.68	139.52	14.5	4.8	7.7	1.5	1.3
+400	381.57	199.55	182.02	18.9	17.7	175.7	0.7	1.1
Fines	663.76	294.19	369.57	38.4	3.9	18.4	3.7	2.1
Total	1585.45	621.90	963.55	100.0	9.0	166.2	2.1	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091017

TAN TSF-03

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	22.71	20.77	1.94	0.3	8.8	14.0	9.2	9.2
+ 10	16.95	14.40	2.55	0.4	7.9	12.2	17.5	13.9
+ 40	28.15	24.53	3.62	0.6	9.8	16.4	37.3	24.4
+100	67.96	24.33	43.63	7.1	7.6	8.5	4.5	7.6
+200	138.13	24.40	113.73	18.5	5.1	8.1	1.4	3.4
+400	80.97	20.35	60.62	9.9	15.3	8.1	3.7	3.4
Fines	681.64	293.75	387.89	63.2	5.5	8.5	3.6	3.6
Total	1036.51	422.53	613.98	100.0	6.6	8.5	3.6	

Sample Log Number: 091017 after attrition

TAN TSF-03

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	128.41	127.22	1.19	0.1	9.4	14.9	12.1	12.1
+ 10	92.16	91.39	0.77	0.1	11.2	18.1	59.2	30.6
+ 40	135.05	127.05	8.00	0.8	9.9	189.6	23.7	25.1
+100	149.17	91.30	57.87	5.9	5.1	21.4	2.9	6.1
+200	266.68	126.63	140.05	14.4	4.1	40.2	1.9	3.3
+400	223.31	126.85	96.46	9.9	5.0	61.3	3.9	3.5
Fines	1257.21	587.75	669.46	68.7	10.1	48.6	13.0	10.0
Total	2251.99	1278.19	973.80	100.0	8.5	48.2	10.0	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091513

TAN TSF-07

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	150.18	131.96	18.22	1.7	14.5	168.0	155.4	155.4
+ 10	37.82	24.66	13.16	1.2	28.5	375.7	405.4	260.2
+ 40	351.66	298.74	52.92	5.0	6.3	14.3	405.4	351.4
+100	347.64	298.42	49.22	4.7	6.1	7.5	268.9	321.0
+200	198.68	129.73	68.95	6.5	5.3	18.5	99.5	245.5
+400	166.70	82.26	84.44	8.0	6.0	29.5	65.7	192.6
Fines	1113.73	345.73	768.00	72.8	18.2	271.6	281.1	257.0
Total	2366.41	1311.50	1054.91	100.0	15.3	210.0	257.0	

Sample Log Number: 091513 after attrition

TAN TSF-07

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	363.36	305.81	57.55	7.8	39.7	338.3	142.2	142.2
+ 10	324.83	307.34	17.49	2.4	24.1	399.1	500.0	225.6
+ 40	261.79	217.92	43.87	6.0	45.5	653.2	362.2	276.0
+100	119.43	81.95	37.48	5.1	6.5	7.8	302.7	282.4
+200	139.39	82.21	57.18	7.8	6.0	7.4	128.4	241.1
+400	264.85	199.96	64.89	8.8	6.7	62.6	97.8	207.7
Fines	527.75	70.73	457.02	62.1	24.5	148.2	104.3	143.5
Total	2001.40	1265.92	735.48	100.0	23.0	173.5	143.5	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 090313

TAN TSF-09

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	558.70	103.64	455.06	30.4	219.4	6711.7	8189.2	8189.2
+ 10	104.61	24.76	79.85	5.3	410.8	13063.1	13729.7	9016.3
+ 40	272.11	195.60	76.51	5.1	725.2	25315.3	28918.9	11506.8
+100	372.23	191.48	180.75	12.1	1684.7	56756.8	61081.1	22818.2
+200	354.84	194.90	159.94	10.7	2319.8	80630.6	70270.3	30789.4
+400	293.00	193.62	99.38	6.6	3238.7	111261.3	88918.9	36283.4
Fines	518.07	72.45	445.62	29.8	12342.3	416216.2	462162.2	163047.7
Total	2473.56	976.45	1497.11	100.0	4465.6	150770.8	163047.7	

Sample Log Number: 090313 after attrition

TAN TSF-09

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	404.79	104.30	300.49	25.4	123.0	3828.8	2864.9	2864.9
+ 10	89.16	24.30	64.86	5.5	165.8	5225.2	10162.2	4160.3
+ 40	89.67	20.79	68.88	5.8	815.3	25540.5	18864.9	6492.9
+100	334.79	192.97	141.82	12.0	1220.7	38198.2	44324.3	15806.7
+200	327.23	193.30	133.93	11.3	2121.6	68018.0	71081.1	26233.6
+400	112.17	20.53	91.64	7.7	3085.6	103603.6	120000.0	36952.9
Fines	454.41	72.15	382.26	32.3	12342.3	388738.7	464864.9	175120.3
Total	1812.22	628.34	1183.88	100.0	4698.0	148553.1	175120.3	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.



Sample Log Number: 083119

TRA TRA-13

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1722.40	143.52	1578.88	69.2	26.2	549.5	16.7	16.7
+ 10	439.82	294.57	145.25	6.4	169.4	8828.8	41.6	18.8
+ 40	288.95	79.87	209.08	9.2	40.8	878.4	82.7	25.7
+100	521.18	295.70	225.48	9.9	5.5	381.1	80.8	31.5
+200	87.22	20.68	66.54	2.9	11.0	244.6	802.7	54.5
+400	58.34	24.28	34.06	1.5	57.2	1049.5	856.8	66.6
Fines	36.23	14.37	21.86	1.0	19.0	31396.4	20459.5	262.1
Total	3154.14	872.99	2281.15	100.0	34.6	1384.4	262.1	

Sample Log Number: 083119 after attrition

TRA TRA-13

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1392.16	138.72	1253.44	56.7	142.3	6891.9	6.8	6.8
+ 10	308.12	79.84	228.28	10.3	500.0	24909.9	14.6	8.0
+ 40	373.98	79.92	294.06	13.3	17.7	289.2	57.8	16.3
+100	273.08	79.55	193.53	8.8	112.2	2991.0	243.8	38.6
+200	95.82	20.73	75.09	3.4	133.3	3265.8	551.4	57.5
+400	98.65	24.47	74.18	3.4	89.6	1306.3	775.7	82.6
Fines	115.40	24.58	90.82	4.1	37.4	743.2	675.7	107.0
Total	2657.21	447.81	2209.40	100.0	153.7	6969.5	107.0	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

Sample Log Number: 091019

TRA WWP

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	1231.35	360.73	870.62	63.8	5.0	17.5	0.9	0.9
+ 10	228.72	126.38	102.34	7.5	4.1	6.3	3.6	1.1
+ 40	242.89	127.30	115.59	8.5	5.9	8.3	8.5	1.9
+100	239.07	126.71	112.36	8.2	5.8	8.2	19.7	3.6
+200	132.33	90.28	42.05	3.1	9.6	7.8	61.1	5.5
+400	132.98	89.89	43.09	3.2	3.9	7.1	70.3	7.7
Fines	208.53	130.34	78.19	5.7	4.7	7.5	11.3	7.9
Total	2415.87	1051.63	1364.24	100.0	5.2	13.9	7.9	

Sample Log Number: 091019 after attrition

TRA WWP

Particle Size Distribution

Radionuclide Distribution (pCi/g)

Sieve	Gross	Tare	Net	Wt %	Alpha	Beta	Cs-137	Avg Cs
+ 4	116.50	20.40	96.10	18.3	2.7	20.4	0.0	0.0
+ 10	226.67	132.15	94.52	18.0	4.8	6.7	1.9	1.0
+ 40	231.85	129.83	102.02	19.4	5.3	8.3	2.7	1.6
+100	337.93	217.23	120.70	23.0	4.5	7.8	8.4	3.6
+200	181.21	127.27	53.94	10.3	4.4	8.1	31.1	6.7
+400	185.13	129.35	55.78	10.6	6.7	29.3	47.8	11.1
Fines	84.02	81.75	2.27	0.4	18.6	139.6	118.9	11.6
Total	1363.31	837.98	525.33	100.0	4.7	12.9	11.6	

Average Cs = Calculated weighted average concentration of cesium for composite soil fraction greater than or equal to sieve size shown. For example, activity shown on +40 mesh line is the average activity for all materials above 40 mesh.

## **APPENDIX B**

### **Summary of Soil Characteristics and Soil Washing Technologies**

**SUMMARY OF SOIL CHARACTERISTICS  
AND  
SOIL WASHING TECHNOLOGIES  
FOR SOILS AT THE  
IDAHO NATIONAL ENGINEERING LABORATORY**

OCTOBER 1993  
Revision 1

Prepared for  
Westinghouse Idaho Nuclear Company, Inc.  
by  
H&R Technical Associates, Inc./ Halliburton NUS Corporation  
under Contract 226478

## TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION .....	1
2. SOIL CHARACTERISTICS .....	1
2.1 Effect of Soil Characteristics on Soil Washing .....	2
2.2 Soil Characteristics at INEL .....	3
3. COMMERCIALY AVAILABLE TECHNOLOGY .....	4
3.1 Grinding .....	4
3.2 Attrition .....	5
3.3 Sieving .....	5
3.4 Hydroclassification .....	6
3.5 Froth Flotation .....	6
3.6 Electrostatic .....	7
4. TECHNOLOGY UNDER DEVELOPMENT .....	7
4.1 Magnetic Separation .....	8
4.2 Chemical Extraction .....	8
4.3 Selective Leaching .....	9
4.4 Cationic Flotation .....	10
4.5 Electrokinetic Soil Processing .....	11
5. COMMERCIAL VENDORS .....	11
5.1 Brice Environmental Services Corporation (BESCORP) .....	11
5.2 Scientific Ecology Group (SEG) .....	12
5.3 AWC, Inc. - Lockheed Environmental Systems .....	13
6. CONCLUSIONS .....	14
BIBLIOGRAPHY .....	16
APPENDIX: Soil Washing Technology Matrix .....	23

## **1. INTRODUCTION**

This report presents information on soil washing technologies that could be used to remediate the large volume of contaminated soil that exists at the Idaho Chemical Processing Plant (ICPP) and other Idaho National Engineering Laboratory (INEL) sites. Contaminants in the soil are predominantly cesium 137, strontium 90, cobalt 60, and uranium. Concerns over the difficulty and costs associated with managing this contaminated soil have generated interest in reducing its volume. The soil washing process is a common method of accomplishing this goal.

The objective of soil washing is to separate the noncontaminated soil from the contaminated soil. Soil washing can be effective since in many contaminated soils only a small amount of soil, dispersed throughout the whole volume, actually contains the contaminants. Under some conditions, only the surface of the soil particles is coated with contaminants. Under other conditions, contaminants occur as discrete particles. Separating the contaminated soil from the noncontaminated soil can potentially reduce the contamination in the remaining volume of soil to acceptable levels. Once separated, the contaminated soil fraction can be further treated or stored for later disposal. (Waste treatment techniques such as MAGSEP, RHM 1000, bioadsorption, vitrification, and some other soil decontamination processes considered to be mixed waste treatment processes are not discussed in this report.)

In Section 2 of this report, an overview of the soil characteristics at the INEL is provided. Commercially available soil washing technologies--technologies that will probably be of primary interest to soil remediation efforts at INEL owing to their timely availability--are reviewed in Section 3. Soil washing technologies that are currently under development are reviewed in Section 4. Vendors and their processes are discussed in Section 5. Conclusions are stated in Section 6. A reference matrix of separation and treatment technologies is provided in the appendix.

## **2. SOIL CHARACTERISTICS**

In subsection 2.1, the effects that soil characteristics can have on different soil washing techniques are explained. In subsection 2.2, the specific soil characteristics at the INEL sites are reviewed.

## **2.1 Effect of Soil Characteristics on Soil Washing**

The use of soil washing technology to separate radionuclides from soils is highly dependent on the specific characteristics of the soil to be treated. Characterization of representative soil samples provides the initial information to determine if volume reduction is technically feasible.

Characterization identifies unique physical properties of the soil constituents that can be used to separate contaminated soil particles from clean soil. Some of the soil properties that may affect the soil washing process are density, size distribution, moisture content, toughness of agglomerates, buffering capacity, reduction and oxidation potential, cation exchange capacity, organic carbon content, and pH.

A common first approach to soil washing begins with breaking up agglomerates by liberating the individual soil particles and then separating the soil particles by size. The specific particle liberating technique or techniques used depend upon soil characteristics, such as toughness of the agglomerates. Particle liberation techniques include washing, scrubbing, attrition, surface de-bonding, crushing, and grinding. Equipment used for particle liberation includes trommels, washers, screw classifiers, grinders, and mills. Once the agglomerates are broken, particles can be separated by size. Commonly used equipment for size separation includes screens, sieves, mechanical classifiers, nonmechanical hydrodynamic classifiers, jigs, shaking tables, drougts, sluices, and flotation machines.

Once the soil particles are separated, the distribution of radionuclides among the different soil size fractions and how the radionuclides are attached to the soil particles can be determined. Characteristics that affect the way radionuclides are attached include buffering capacity, reduction and oxidation potential, cation exchange capacity, organic carbon content, and pH. These characteristics are used to determine which techniques may be appropriate for particle separation and particle liberation by chemical means.

The importance of proper characterization for the selection of a soil washing process was stated in a paper on the feasibility of soil washing at INEL that was recently presented at the International Topical Meeting of the American Nuclear Society. Gombert and Bosley stated that "some contaminated soils and sludges may also pose a unique problem for soil washing because the contaminants do not always exist as individual particles. Because many contaminants are derived from aqueous solutions, they contaminate the soils at an atomic level. Also the contaminants are not limited

to transition and heavy metals but include alkalies and alkaline earth fission products that are chemically analogous to natural soil constituents that make up parts of the soil matrix."

## **2.2 Soil Characteristics at INEL**

The following section provides an overview of the soil conditions at various Waste Area Groupings (WAGs) at INEL. The information presented by no means represents the totality of data available from the numerous studies conducted at the site. Instead, the information illustrates the range of soil conditions found at a particular WAG as well as soil variability found on a larger scale when comparing soil conditions at the various WAGs. The information provides an initial screening of the suitability of soils for the various treatment technologies being investigated.

EG&G Idaho assessed the surface soils at active EG&G Idaho facilities in 1989 and 1990. The intent of the study was to create a comprehensive reference on the properties, metals, and radionuclide content of surface soils at active, nonwaste-management EG&G Idaho facilities. The study encompassed four WAGs: WAG 1, Test Area North (TAN); WAG 2, Test Reactor Area (TRA); WAG 4, the Central Facilities Area (CFA); and WAG 5, the Power Burst Facility (PBF). One objective of the study was to determine if a correlation exists between radionuclide and metal concentrations and the specific soil types associated with various landforms. The soil characteristics presented in the EG&G Idaho report are summarized in Table 1. In the "Interval sampled" column, the first entry for each WAG is for composited surface soil samples collected from gridded locations. The next two entries are for soil samples collected at the surface and subsurface of various landform types (e.g., lava plain, alluvial plain, lake bed). The report concluded that no correlation between soil type and radionuclide concentration was observed.

In 1991, the University of Utah conducted a study titled *Particle Characterization of Contaminated Soil*. Contaminated soils were characterized and the nature of the association of the toxic and radioactive metals with the soil components was investigated. One conclusion of the study was that most radioactivity was present in the minus 100 mesh size fraction for both sludge and dirt samples investigated. The EG&G Idaho study indicates that approximately one half of the INEL soils are below the 100 mesh particles size fraction. These results indicate that contaminated INEL soils may be amenable to volume reduction through soil separation techniques.



Table 1. INEL Soil Characteristics

WAG	Interval sampled	Number of samples	Grain size distribution			Cation exchange capacity	Organic carbon
			% Sand	% Silt	% Clay		
TAN (1)	Surface	18	19.2-50.0	34.4-54.3	12.0-31.7	14.62-27.07	0.37-1.94
	Surface	7	2.3-53.4	25.9-54.1	18.4-43.8	12.46-30.42	0.94-1.52
	Subsurface	8	0.0-46.0	30.6-68.9	12.0-37.7	7.50-33.31	0.77-1.51
TRA (2)	Surface	15	53.1-78.8	13.8-37.7	5.1-12.2	8.33-17.25	1.13-2.04
	Surface	6	55.2-85.8	10.4-36.1	4.2-9.5	8.79-15.91	0.50-1.51
	Subsurface	5	49.3-58.2	31.8-38.5	6.2-12.2	16.42-19.42	0.75-1.05
CFA (4)	Surface	17	61.2-85.0	14.1-31.6	5.1-10.2	6.47-11.45	0.71-1.87
	Surface	11	13.5-75.4	10.9-66.5	7.2-32.7	8.48-21.67	0.13-1.63
	Subsurface	8	14.0 - 70.4	21.4-50.4	8.2-32.1	12.01-26.52	0.29-1.11
PBF (5)	Surface	19	62.2-86.7	5.1-30.6	5.1-11.7	7.79-13.72	0.61-2.27
	Surface	8	60.6-83.5	8.8-31.6	5.4-13.8	8.28-13.59	0.58-2.37
	Subsurface	7	50.5-85.1	8.5-35.6	6.3-19.4	7.58-17.47	0.26-1.08

### 3. COMMERCIALY AVAILABLE TECHNOLOGY

Some of the technologies currently used by industry are described in this section. The described technologies are grinding, attrition, sieving, hydroclassification, froth flotation, and electrostatic separation. Most of these technologies have been adapted from the mining industry and are based primarily on simple physical separation. Since most soil washing vendors use a combination of the various technologies, tailored to suit the needs of each site, brief descriptions of how vendors have applied these technologies are provided in Section 5.

#### 3.1 Grinding

Grinding is the technique of reducing material, either selective size fractions or all size fractions, to a smaller size fraction. This is accomplished by mechanical energy, either using an external medium (balls or rods) or autogenously (particles grinding other particles). Grinding can be performed wet or dry depending on what processes precede or follow the grinding operation.

### **3.2 Attrition**

In this method, mechanical action removes contamination by rubbing (or scrubbing) of larger particle size fractions (greater than 230 $\mu$ m), like stones or pebbles. The purpose of attrition milling is to remove the surface of the particles, which may be contaminated. Scrubbing can be accomplished by using equipment such as a rotating mill, vibratory grinder, or attrition mill. Often, a solvent is added to accelerate or enhance the scrubbing process.

### **3.3 Sieving**

Sieving separates strictly on the basis of particle size and can be used on either wet or dry soils. Dry screening passes the soil through progressively smaller screens to separate the soil into different size groupings. Wet screening sprays the soil with water while passing the soil through the screens. Wet screening is used more often than dry screening because the water suppresses static charge buildup and dust, thereby reducing radioactive dust hazards and enhancing separation of fines from larger particles. The major advantage to this technology is the ease and cost effectiveness of operation.

Often an anomalous distribution of contaminants versus particle size can be identified. This anomalous distribution is referred to as a "split." If a split can be identified, then soil decontamination can be performed strictly on the basis of size separation.

Sieving is a common technology that is usually considered for the first stage of a soil washing system.

### **3.4 Hydroclassification**

When size separation of fine particles is desired, hydroclassification is frequently used. This technology is based on the differences in settling rates of various particles (Stokes Law). In response to the motive force of the water, particles of different specific gravities arrange themselves according to size and specific gravity. Unsized feeds can be used, but classified feeds operate more efficiently. Several types of equipment have been developed to accomplish hydroclassification, including hydrocyclones, selective mineral separators, and counter flow separators.

The hydrocyclone, one of the more common sizing devices, uses a conical chamber. The soil and water slurry is pumped into the unit tangentially at the widest part of the cone and, after some

residence time, the coarse product discharges at the point of the cone and the fine product discharges at the top center of the cone. As a consequence of the rotational fluid-solid motion, particles are separated with much greater force than in other gravitational separation devices.

Hydroclassification is very effective at achieving a discrete separation between two particle size fractions. If a preliminary wet screening experiment demonstrates that radioactive contaminants are anomalously distributed with respect to particle size, the hydroclassifier can be used to take advantage of this split.

### **3.5 Froth Flotation**

Froth flotation is a technology used to separate the selective mineral and metallic particles from soils. For this technique to work, the soil needs to be a specific size fraction.

Soil enters the process tank as a slurry of soil and water. In the tank, chemical reagents are added to the slurry to cause the specific mineral or minerals in the soil to become hydrophobic (water repelling). Then the slurry enters a flotation tank where air or another gas injected into the slurry causes the hydrophobic materials to float to the top of the tank, where they are removed. The remaining material exits the bottom of the flotation tank. The addition of reagents can be controlled to make it possible to separate specific mineral phases or metallic particles from the soils.

This technology is ideally suited for soils where the contamination is associated with specific minerals or metallic particles. (If the contaminants are found to be predominantly concentrated in clays, then a cationic floatation process as described in Section 4.4 can be used.) Froth flotation is employed by several companies, including the Ecology Group.

### **3.6 Electrostatic**

Electrostatic separation is based on the varying conductivity of particles. Dry particles are subjected to controlled electrical currents before entering an electrostatic field. Conductive particles are not affected or are repelled to some degree by the electrode producing the charge. Nonconductive particles will be attracted to the electrode in varying degrees. In the mining industry, electrostatic separation of minerals is used extensively to treat beach sands.

Electrostatic separation has several limitations when applied to soils. The technology is not well suited for sorting soils with a high percentage of fines or soils with a wide range of particle sizes.

The technology works optimally when the feed is one particle layer thick, thus limiting the effectiveness for fines owing to the difficulty of layering the fines. Since the electrostatic charge of the particle is so minute, a larger particle will have less charge by mass than a smaller particle and, hence, attract the smaller particle. The result is that larger particles are more readily missorted.

The use of electrostatic separation at INEL would require resolving problems with exposure to potentially contaminated dust, particle size limitations, and static adherence of smaller particles to larger particles. Since other technologies are available that may be better suited for the INEL soils, electrostatic separation is not recommended.

#### **4. TECHNOLOGY UNDER DEVELOPMENT**

The technologies presented in this section are magnetic separation, chemical extraction, selective leaching, cationic flotation, and electrokinetic soil processing. All of these technologies are still in various stages of development. Although these technologies are promising, most have exhibited only limited success thus far. These technologies are often site-specific, so that additional analysis and experimentation are required to apply a technology developed at one site to another site or contaminant.

##### **4.1 Magnetic Separation**

High Gradient Magnetic Separation (HGMS) is a physical separation technique based on the magnetic susceptibility of contaminated particles. HGMS relies on the paramagnetic properties of the particles to be separated. If the particles do not exhibit sufficient paramagnetic properties, then separation cannot occur. Most soil components are diamagnetic (nonmagnetic), whereas elements in the actinide series, including uranium and plutonium, are paramagnetic (somewhat magnetic). The difference in magnetic properties allows separation of the paramagnetic elements by capturing them in a ferromagnetic matrix, like steel wool. Research conducted by AWC-Lockheed typically involves fused metallic particles, which are easier to separate by using magnetic separation.

The technology is presently used in Georgia's kaolin industry to remove impurities from the white clay used to coat paper. AWC-Lockheed and Los Alamos National Laboratory are researching the feasibility of applying this technology to the removal of radioactive contaminants from soil.

HGMS combined with gravimetric separation is estimated to result in a 90% reduction in uranium- or plutonium-contaminated soil volume.

Unfortunately, several fission products present at INEL, such as cesium and strontium, are not paramagnetic and will remain in the soil unless they are attached to paramagnetic particles in the soil. Magnetic separation experiments performed by the University of Utah showed that only a very small percentage of the soil at INEL was magnetic or weakly magnetic. Since neither the contaminants nor the soil particles exhibit strong magnetic properties, HGMS will not work with INEL soils.

#### **4.2 Chemical Extraction**

Chemical extraction attacks the bonding mechanism of a particular contaminant. The contaminant is either specifically released into the solution or the substrate is dissolved by the extractant solution. A specific solvent that will release the contaminant or contaminants of interest into solution may be selected. Solvents range from water or water with surfactants (soaps) to strong acids or bases. Contaminated soil is fed into a hopper and then mixed with the solvent to form a slurry. The soil is continuously leached by the solvent until the soil is removed from the hopper, dried, and returned to the site. The leachate from the soil must be evaluated for resulting secondary wastes and treated or disposed accordingly.

A large variety of chemical extraction solvents and applications is available. However, many solvents create hazardous secondary wastes or are best suited for use with a limited number of contaminants. Chemical extraction may not be suited for INEL soils because many of the contaminants at INEL are chemically similar to naturally occurring minerals.

Chemical extraction can also be used in the form of sequential extraction. Sequential extraction is typically used as an evaluation method to identify a reagent or combination of reagents that adequately remove the contaminants from the soil. The method was developed to investigate the removal of multiple contaminants from soil when the physical and chemical properties of the contaminant and the soil are so similar that physical separation methods are not feasible. Emphasis is placed on using less harsh extractants so that soil dissolution and secondary waste generation are minimized. In sequential extraction, multiple extractions are performed on the same batch of soil, each extraction focusing on extracting one soil contaminant at a time. A continuum of extractants is used, starting with the least aggressive chemistry and progressing to the use of mineral acids.

Gombert and Bosley note that removing metals by means other than size classification is extremely site- and species-specific. Their experiments with sequential extraction indicated that sequential extraction was ill suited for the TRA soil samples they selected. Chemical extraction very often results in some type of secondary waste. Chemical extraction may succeed at removing the contamination from the soil but may generate another waste stream that is just as costly to treat or dispose. Chemical extraction techniques are not recommended for INEL soils.

#### **4.3 Selective Leaching**

Carbonate leach solutions are frequently used to recover uranium from its ores. The process takes advantage of a very stable complex that exists between the uranyl and carbonate ions. For example, many uranium minerals will react with carbonate solutions, under proper conditions, to produce the soluble uranyl carbonate complex. Carbonate leach solutions have several advantages over more aggressive acid extraction solutions. Since few minerals other than uranium, vanadium, and some silicates are attacked by the carbonate solutions, comparatively fewer soil components are attacked. In addition, the leachate is predominantly uranium so that the reagent can be regenerated for further use.

Selective leaching of uranium from uranium-contaminated soils is being conducted as part of the Fernald Uranium Soils Integrated Demonstration, funded through DOE's Office of Technology Development. Three soils and a sediment contaminated with uranium were used to determine the effectiveness of sodium carbonate and citric acid leaching to remove uranium to below regulatory levels. Research to date shows that uranium can be extracted from Fernald and Oak Ridge Y-12 soils without degrading the soils' physicochemical characteristics or generating a hazardous secondary waste stream. Work is still needed to increase the process rates. Current rates require large reaction vessels or slow process load times.

This technology is not yet fully developed for use at other sites. Pending further development of the uranium leaching methods, methods would also need to be developed to leach the contaminants of concern at INEL (cesium, strontium, plutonium, and cobalt), which are not chemically similar to uranium. Gombert and Bosley's experiments with sequential extraction of TRA soils found selective leaching could not meet site requirements. The contaminants proved to be too similar to other minerals in the soil or actually part of the soil matrix, which rendered selective leaching ineffective.

#### **4.4 Cationic Flotation**

This technology takes advantage of the anionic surface of clay particles, which enables separation of the clay fraction from the remainder of the fines. A cationic flotation agent such as an amine can be used to float the clay material in a conventional flotation and scrubbing technology. By adding a quartz suppressor, the soil can be scrubbed at high speeds that abrade the rocks. The abrasion causes an increase in the fine fraction, but the suppressor keeps the fines from floating with the clay.

Research into cationic flotation is still in progress. This technology may be useful for separating the clay fraction from INEL soils if other techniques prove unsuccessful, but only if the majority of contaminants present in the INEL soils is present in the clay fraction. Preliminary results indicate that the clay fraction at INEL ranges from 5% to 40%. Therefore, a particle size versus contamination study is needed to evaluate the distribution of radioactive components. If the radioactive components appear to be concentrated in the fines and the fines are determined to be made up of clay particles, then cationic flotation may be a useful technology.

#### **4.5 Electrokinetic Soil Processing**

An exact description of this technology was not available. Electrochemical or electrokinetic separation is being investigated jointly by U.S. EPA and Electrokinetics, Inc. The process uses electrodes placed into the ground and an electrolyte to convey the contaminants to the electrodes and out of the soil. Preliminary results seem to indicate that the process can be used to remediate many types of soils. Louisiana State University (LSU) is investigating the feasibility of removing radionuclides by using this technology.

The technology is still under development but may not be applicable to INEL soils because some contaminants were deposited in ionic form. In addition, cesium tends to behave much like potassium and sodium in soils, which makes separation of cesium from other elements difficult. The technology also lacks a conclusive means of solubilizing the contaminant. LSU experiments suggest that the electric current induces an acid sweep to solubilize the contaminants, but INEL soil tends to be basic and may neutralize the acid sweep. In addition, the electrokinetic technology requires that the soil be wet enough to not only conduct the electric current but also to allow the ions to move to the

anode or cathode. INEL soil is very arid and would not accommodate the electric current without the addition of water, which could cause the contaminants to migrate.

## **5. COMMERCIAL VENDORS**

This section identifies three commercial vendors and provides a brief description of each vendor's soil washing process. Often, a process will combine several of the technologies described in Sections 3 and 4.

### **5.1 Brice Environmental Services Corporation (BESCORP)**

The BESCORP Soil Washing System (BSWS) is a water-based process for mechanically scrubbing ex situ soils to remove radioactive contaminants. The BSWS employs a patented hydraulic separations device and several other treatment methods, depending on the contaminant types. The treatment methods include particle size separation, gravity separation, attrition scrubbing, and contaminant dissolution in the wash solution. The separation device, called a counter flow separator, has been used since 1990 to remove gold-bearing fines at a 150-ton-per-hour placer gold mining operation in Alaska.

In the BESCORP system, a slurry of fines, sand, and pebbles enters the top of the separating chamber, where very fine particles are maintained in suspension by a slight upward flow of water. This suspension is discharged to a clarifier for further concentration of the fines and recovery of the water for recycling. Larger and denser particles settle to the bottom of the chamber, where they encounter a higher velocity stream of upflowing, clean water. The largest and densest particles that enter this stream achieve a settling velocity greater than the water velocity and settle to the bottom of the separator. A spiral classifier is subsequently used to separate the settled material from the water.

Particles that are entrained by the higher velocity water stream are discharged to a second separation system, where lower velocity flows allow collection of washed particles of a slightly smaller size, or cut. Several of the counter flow separators can be used in series, thereby allowing multiple size separations as needed. Once the fines have been separated, the fractions may be treated further or discarded.



BESCOP has built a 20-ton-per-hour pilot plant that is mounted on a small trailer (8 feet by 40 feet) and has demonstrated this unit on clean soil at a site near Hanford. As a pilot project, BESCOP demonstrated the ability of their operation to precisely separate soil at a randomly selected size of 150 mesh. The sharpness of the 150-mesh split achieved in that demonstration reflects the ability of the BESCOP soil washing technology to selectively separate particles of a given size from soil. Since preliminary University of Utah studies indicate that contaminants are concentrated in the fines (400 mesh), the BSWS may be able to take advantage of this trend by separating the contaminated fines from the remaining soil fractions.

## **5.2 Scientific Ecology Group (SEG)**

The SEG process is based upon commonly available mineral treatment processes that consist of several operating units tied together in an integrated process. SEG uses a combination of particle separation by size and density or both and chemical extraction using either soaps or extraction solutions to clean the contaminated particles themselves. The process is modified to fit the needs of the site by changing the extraction solutions and particle separation method. Some of the equipment available includes an attrition scrubber, a mineral jig, a froth floatation unit, and an ion exchange system.

One commercial-scale, one laboratory-scale, and two pilot-scale soil washing projects have been successfully carried out with radionuclide-contaminated soil. The commercial scale project and one of the pilot scale projects were performed at a uranium mining site in Bruni, Texas. The laboratory scale project and the other pilot scale project were performed at a mixed waste site in Oak Ridge, Tennessee.

At the Bruni site, uranium and radium are currently being removed by SEG's commercial 20-ton-per-hour system. Commercial operations at Bruni began in March of 1992. Prior to commercial operations, laboratory-scale and pilot-scale projects were successfully completed on soils from the site. Better than 99% of the feed soil at Bruni is being returned to the field. Contaminated root hairs and ion exchange resin beads are the only additional waste products not returned to the field. The root hairs and resin beads represent less than 1% of the feed soil. These waste products will be incinerated at the SEG Oak Ridge Facility or buried at a qualified burial site. Analysis by Texas A&M showed

that all of the washed soil samples were capable of growing native grasses. Only additional potassium and phosphorus may be necessary to return the soil to the same fertility level as the unwashed soil.

The SEG soil washing process decontaminated oil landfarm soil and river and sewer sediments from the Oak Ridge Y-12 Plant. The oil landfarm soil was contaminated with a mixture of grease, PCBs, and uranium. The river and sewer sediments were contaminated with a mixture of mercury and uranium. Both soils were considered a mixed waste.

### **5.3 AWC, Inc. - Lockheed Environmental Systems**

The AWC-Lockheed transuranic (TRU) cleaning process uses a device called the Selective Mineral Separator to remove fines that are at least twice as dense as the soil matrix in which they are contained. The technology has been shown to be effective in decontaminating TRU elements at the Johnston Atoll and depleted uranium China Lake soils. Separation is achieved by pulsing a bed of contaminated soil with jets of water. The denser particles settle faster and eventually pass through a supporting bed of steel shot and into a collection chamber. Length of time and jet velocity can be varied to achieve the desired split. The pilot plant at China Lake is similar to the one used at Johnston Atoll with the addition of attrition scrubbing and acid leaching. In testing, the Selective Mineral Separator system alone (the Johnston Atoll system) achieved an 80% volume reduction. The addition of the leaching process is expected to increase the volume reduction to 90%.

In both situations, the contaminants existed as pieces of metal, which made separation by gravitational means easy. The contaminants at most INEL sites do not exist in the form of discrete metal particles; therefore, this process is not applicable. However, the conveyor system demonstrated on Johnston Atoll that removes discrete pockets of soil or particles may provide some volume reduction. The effectiveness of this method cannot be predicted without further testing of INEL soils with the conveyor system.

## **6. CONCLUSIONS**

The water-based soil separation and decontamination methods presented here are some of the safer ways to handle and decontaminate radioactive soils. Water is not only an effective solvent but also helps to prevent dust and static charge problems. Many of the processes have proven to be very successful with the various soils and contaminants tested thus far.

Enough information is available to justify requesting vendors to investigate further. Most vendors perform their own particle characterization studies because of the proprietary nature of their processes. If INEL intends to have some of the work performed by vendors, vendors should be contacted and requested to evaluate the effectiveness of their process with INEL soil samples. Most of the vendors can sample and analyze soils at cost and then provide cost and volume reduction estimates. Some vendors can even perform the analysis on-site, if needed.

Both SEG and BESCOP can perform laboratory-scale treatability studies to determine the efficiency of the various separation techniques and provide a preliminary cost estimate. Once the laboratory tests are completed, the next phase would be to carry out a field demonstration to establish field operating conditions and a more exact cost estimate.

Benefit would also be realized by contacting some of the institutions conducting soil washing research. By working with such institutions, emerging technologies capable of decontaminating or reducing the volume of the contaminated soils at INEL could be identified.

**BIBLIOGRAPHY**

Anon., "Technology Notebook", p. 88, *HAZMAT World*, May 1993.

AWC-Lockheed, Inc., "TRUclean System Demonstrated on Depleted Uranium at China Lake," Las Vegas, Nevada.

Avens, Larry, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 17, 1993.

Bennet, Sarah, GTS-Duratek, Columbia, Maryland, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 25, 1993.

Brice Environmental Services Corporation, *BESCORP Qualifications for Soil Washing Services*, Fairbanks, Arkansas.

Carder, William, Scientific Ecology Group, Inc., Kingston, Tennessee, Telephone Conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 14, 1993.

Chapin, J. A., *Soil Decontamination, Final Report*, PR-W-79-027, EG&G Idaho, Inc., September 1979.

Chi, L., Kimmitt, R. R., and Madden, T. H., *Summary Report of Technology Demonstrations on Y-12 Mixed Waste Soils*, Y/WM-108, Oak Ridge Y-12 Plant (Martin Marietta Energy Systems), March 1992.

Clegg, John W., and Foley, Dennis D., *Uranium Ore Processing*, Addison-Wesley Publishing Company, Inc., Reading, 1958.

Cummins, Arthur B., and Given, Ivan A., *SME Mining Engineering Handbook*, Vol. 2, Society of Mining Engineers, New York, 1973.

Eagle, Michael C., et al., "Soil Washing for Volume Reduction of Radioactively Contaminated Soils," *Remediation*, 327-344, (Summer 1993).

Eagle, Michael, Environmental Protection Agency Office of Radiation Programs, Washington, D.C., telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 24, 1993.

Faison, Brendalyn, Martin Marietta Energy Systems Bioremediation Group, Oak Ridge, Tennessee, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 17, 1993.

Francis, C.W. et al., *Selective Leaching of Uranium from Uranium-Contaminated Soils: Progress Report 1*, ORNL/TM-12177, DOE Office of Technology Development, February 1993.

Francis, C. W., Martin Marietta Energy Systems Soils and Sediments Division, Oak Ridge, Tennessee, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 20, 1993.

Freeman, Harley D., Battelle Pacific Northwest Laboratories, Richland, Washington, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 17, 1993.

Freysted, Dr. Bill, COGNIS Incorporated, Santa Rosa, California, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 18, 1993.

Gerber, M. A., et al., "Soil Washing Results for Mist Waste Pond Soils at Hanford," pp. 511-515 in *Environmental Remediation '91, Cleaning Up the Environment for the 21st Century*, proceedings of the ER'91 Conference at Pasco, Washington, September 8-11, 1991, ed. Donald E. Wood.

Golder Associates, Inc., *Report for Geotechnical Sample Collection and Analysis for Soil and Rock Cores from the Tank Farm Area at the Idaho Chemical Processing Plant*, Golder Associates Inc., Redmond, Washington, 1992.

Golder Associates, Inc., *High-Level Waste Tank Farm Replacement Project Geotechnical Investigation*, Golder Associates, Inc., Redmond Washington, 1992.

Golder Associates, Inc., *Firewater Storage and Pump System Geotechnical Investigation for Westinghouse Idaho Nuclear Company*, Golder Associates Inc., Redmond, Washington, 1990.

Gombert, D., WINCO, Idaho, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 20, 1993.

Gombert, D., and Bosley, J. B., "Soil Washing and Radioactive Contamination," pp. 366-370 in *Nuclear and Hazardous Waste Management Spectrum '92*", proceedings of the International Topical Meeting, August 23-27, American Nuclear Society, Inc., La Grange Park, 1992.

Grant, D. C., and Lahoda, E. J., "Remediation of Uranium and Radium Contaminated Soil Using the Westinghouse Soil Washing Process," in *The 7<sup>th</sup> Annual DOE Model Conference on Waste Management & Environmental Restoration*, proceedings of the 1991 DOE Model Conference at Oak Ridge, Tennessee, October 14-17, 1991.

Grant, D. C., and Lahoda, E. J., "Treatment of Y-12 Plant Mixed Waste Contaminated Soils Utilizing the Westinghouse Soil Washing Process," pp. 139-142 in *Environmental Remediation '91, Cleaning Up the Environment for the 21st Century*, proceedings of the ER'91 Conference at Pasco, Washington, September 8-11, 1991, ed. Donald E. Wood.

Greenman, Bill, GTS-Duratek, Columbia, Maryland, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 19, 1993.

Horton, J. H., and Albenesius, E. L., "Volume Reduction of Plutonium--Contaminated Soil, " *Nuclear Technology*, **30**, 86-88 (July 1976).

Hupka, J., and Miller, J.D., *Particle Characterization of Contaminated Soil--Informal Report*, EGG-WTD-9736, May 1991.

Hupka, J., and Miller, J.D., *Particle Characterization of Contaminated Soil--Final Report*, EGG-WTD-9736, May 1991.

Jones, Craig, Brice Environmental Services Corporation, Fairbanks, Arkansas, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 18, 1993.

Kendrick, Cindy, Martin Marietta Energy Systems Chemical Technology Division, Oak Ridge, Tennessee, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 20, 1993.

Kochen, R. L., Stevens, J. R., and Rutherford, D. W., *Comparative Scrub Solution Tests for Decontamination of Transuranic Radionuclides from Soils*, RFP-3161, Rockwell International Rocky Flats Group, August 1982.

Kochen, Robert L., EG&G Rocky Flats, Inc., Golden, Colorado, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 18, 1993.

Kochen, R. L., and Navratil, J. D., *Decontamination of Soil Containing Plutonium and Americium*, RFP-3139, Rockwell International Rocky Flats Group, March 1982.

Kochen, R. L., McGlochlin, S. C., and Pettis, S. A., *Removal of Actinides from Rocky Flats Soils*, RFP-4479, EG&G Rocky Flats, Inc., September 1991.

Martin, K.L., et al., *Preliminary Assessment of Surface Soils at Active EG&G Idaho Facilities Data Document*, EGG-ESQ-9225, September 1990.

Nuhfer, Kimberly R., "Integrated Demonstration For The Removal of Uranium Substances from Soils," pp. 597-602 in *Environmental Remediation '91, Cleaning Up the Environment for the 21st Century*, proceedings of the ER'91 Conference at Pasco, Washington, September 8-11, 1991, ed. Donald E. Wood.

Olsen, R. L., et al., *Soil Decontamination at Rocky Flats*, pp. 161-72 in *Decontamination and Decommissioning of Nuclear Facilities*, ed. M. M. Osterhout, Plenum Press, New York.

Pegg, I. L., et al., *Development of a Combined Soil Wash/In-Furnace Vitrification System for Soil Remediation at DOE Sites*, Durateck Corporation, Columbia, Maryland.

Robie, Don, TMA/Eberline, Oak Ridge, Tennessee, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 20, 1993.

Roll, Joe, AWC-Lockheed Company, Inc., Las Vegas, Nevada, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 19, 1993.

Scientific Ecology Group, Inc., "SEG Qualifications for Soil Washing Services," *Nuclear Waste Technology*, Pttsburgh, Pennsylvania.

Stevens, John R., EG&G Rocky Flats, Inc., Golden, Colorado, telephone conversation with Jonathan Eckles, H&R Technical Associates, Inc., Oak Ridge, Tennessee, May 18, 1993.



Stevens, J. R., and Rutherford, D. W., *Separation of Transuranic Radionuclides from Soil by Vibratory Grinding*, RFP-3296, Rockwell International Rocky Flats Group, August 1982.

Treat, R. L., Field, J. G., and Freeman, H. D., "Soil Washing: A Promising Technology for the Cleanup of Hanford," pp. 697-701 in *Environmental Remediation '91, Cleaning Up the Environment for the 21st Century*, proceedings of the ER'91 Conference at Pasco, Washington, September 8-11, 1991, ed. Donald E. Wood.

U.S. EPA, *Assessing Federal Data Bases for Contaminated Site Clean-Up Technologies*, 2nd ed., EPA/542/B-92/002, August 1992.

U.S. EPA, *Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites*, EPA/540/2-90/001, January 1990.

U.S. EPA, *Characterization Protocol for Radioactive Contaminated Soils*, EPA/9380.1-10FS, May 1992.

U.S. EPA, *Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation*, 2nd ed., EPA/542/B-92/001, August 1993.

U.S. EPA, *Guide for Conducting Treatability Studies Under CERCLA*, Interim Final, EPA/540/2-89/058, December 1989.

U.S. EPA, *Soil Washing Treatment, Engineering Bulletin*, EPA540/2-90/017, September 1990.

U.S. EPA, *Superfund Innovative Technology Evaluation Program: Demonstration Bulletin, Mobile Volume Reduction Unit*, EPA/540/MR-93/508, April 1993.

U.S. EPA, *Synopses of Federal Demonstrations of Innovative Site Remediation Technologies*. 2nd ed., EPA/542/B-92/003, August 1992.

*Soil Characteristics and Washing Technologies at INEL*  
*Page 21*

---

U.S. EPA, *The Superfund Innovative Technology Evaluation Program: Spring Update to the Technology Profiles*, 4th ed., EPA/540/R-92/012, April 1992.

Wade II, Troy E. and Hall, Gary F., *TRUclean- The Production Scale Soil Remediation Process*, AWC-Lockheed, Inc., Las Vegas, Nevada.

**APPENDIX**

**SOIL WASHING TECHNOLOGY MATRIX**

## SOIL WASHING TECHNOLOGY MATRIX

Technology	Principle	Application	Advantages	Disadvantages
High gradient magnetic separation (HGMS)	Mechanical Separation: based on the paramagnetic properties of radionuclides.	Currently being tested	<ul style="list-style-type: none"> <li>- No secondary waste</li> <li>- Dry or wet process</li> <li>- Applicable to rad. contaminants</li> </ul>	<ul style="list-style-type: none"> <li>- Electrically intensive</li> <li>- Will not work with cesium or strontium</li> <li>- Dewatering required for wet processing</li> </ul>
Bioadsorption	Chemical Treatment: uses microbes to adsorb metals and radionuclides.	Currently being tested	<ul style="list-style-type: none"> <li>- Ideal for water treatment</li> </ul>	<ul style="list-style-type: none"> <li>- Not yet developed for soils</li> <li>- Creates secondary waste (biosludge)</li> <li>- Dewatering required</li> </ul>
Selective leaching	Chemical Treatment: sodium carbonate or citric acid are used to extract uranium from the soil.	Currently being tested	<ul style="list-style-type: none"> <li>- Little change in soil properties</li> <li>- Less harmful than acids</li> </ul>	<ul style="list-style-type: none"> <li>- Slow reaction times</li> <li>- Proven for uranium only</li> <li>- Creates secondary waste</li> </ul>
Aquatic plants	Biological Treatment: Plants absorb heavy metals and radionuclides.	Unknown	<ul style="list-style-type: none"> <li>- No secondary waste (except for plants)</li> <li>- Does not change soil properties</li> <li>- In situ treatment</li> </ul>	<ul style="list-style-type: none"> <li>- Not fully developed</li> <li>- Not suited for arid soil</li> </ul>
Hydroclassification	Mechanical Separation: based on settling rate differences of soil particles and metals.	In use	<ul style="list-style-type: none"> <li>- No secondary waste, if contaminants are not soluble in water</li> <li>- Applicable to rad. contaminants</li> </ul>	<ul style="list-style-type: none"> <li>- Dewatering required</li> <li>- Contaminant must be partitioned</li> <li>- Success is soil and contaminant dependent</li> </ul>
Froth flotation	Mechanical Separation: the slurry is aerated to remove small particles.	In use	<ul style="list-style-type: none"> <li>- Applicable to rad. contaminants</li> </ul>	<ul style="list-style-type: none"> <li>- Soil and Contaminant dependent</li> <li>- May create secondary waste if hazardous chemicals are used</li> <li>- Dewatering required</li> </ul>

### SOIL WASHING TECHNOLOGY MATRIX

Technology	Principle	Application	Advantages	Disadvantages
Chemical binding, precipitation, and separation	Chemical Treatment: uses proprietary powder (RHM 1000) to absorb, adsorb, and chemisorb radionuclides and heavy metals.	Currently being tested	- Secondary waste is stable resin/sludge	- Requires solution form for precipitation of contaminants - No field tests - Creates secondary waste - Dewatering required
Vitrification	Mechanical Treatment: melts soil to a glasslike substance.	Currently being tested	- No secondary waste, except for off-gas. - Waste is very stable, easily stored in any shape - Not soil or contaminant specific	- Not proven - Electrically intensive - Soil not reused - Hazardous off-gas possible
Chemical extraction	Chemical Separation: extracts contaminants in large leaching chamber.	Currently being tested	- Proven in mining industry for many ore/mineral types.	- Highly soil dependent - Creates secondary waste - Dewatering/chemical treatment required
Physical separation	Mechanical Separation System: part of EPA's VORCE Program. Uses attrition and hydroclassification.	Currently being tested	- No secondary waste - Works with rad. contaminants	- Soil dependent - Dewatering require
Vibratory grinding	Mechanical Separation: uses a commercially produced vibratory finisher to abrade and remove contamination on soil particles.	In use	- Can be chemically enhanced - Works with rad. contaminants	- Soil dependent; contaminant must be on surface of particles - Not as selective as other mechanical methods - Potential chemical waste problems.
Wet screening	Mechanical Separation: separates soil particles on the basis of size. Uses water.	In use	- No secondary waste. - Works well with other methods: attrition, hydroseparation - Can be chemically enhanced.	- Soil and contaminant dependent - Contaminant must be segregated in specific size fraction - Dewatering required

### SOIL WASHING TECHNOLOGY MATRIX

Technology	Principle	Application	Advantages	Disadvantages
Attrition scrubbing	Mechanical Separation: soil is scrubbed (jar mill) and fines (slurry) decanted.	In use	<ul style="list-style-type: none"> <li>- No secondary waste</li> <li>- Works well with other methods</li> <li>- Can be chemically enhanced</li> </ul>	<ul style="list-style-type: none"> <li>- Soil and contaminant dependent</li> <li>- Contaminant must be on surface of particles</li> <li>- Dewatering required</li> </ul>
Cationic flotation	Mechanical Separation: uses anionic property of clay to separate it from rest of soil.	In use	<ul style="list-style-type: none"> <li>- No secondary waste if contaminants don't solubilize</li> </ul>	<ul style="list-style-type: none"> <li>- Still under development.</li> <li>- May not work for non-clay soils</li> <li>- Dewatering required</li> </ul>
Electrochemical (or electrokinetic)	Mechanical/Chemical Separation: uses ionic properties of contaminants to cause migration in soil when electrical charge is present.	Currently being tested at LSU, Baton Rouge, LA	<ul style="list-style-type: none"> <li>- No secondary waste</li> <li>- In situ</li> </ul>	<ul style="list-style-type: none"> <li>- Still under development</li> <li>- May not work for some radionuclides</li> <li>- Difficult to verify effectiveness</li> <li>- Not suited for arid or basic soils</li> </ul>
Electrostatic separation	Mechanical Separation: uses electrical conductivity of particles to separate them by varying electrical charges.	Used in mining	<ul style="list-style-type: none"> <li>- No secondary waste</li> </ul>	<ul style="list-style-type: none"> <li>- Potential rad. dust problems</li> <li>- Static charge problems</li> <li>- Limited to specific particle sizes</li> </ul>